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TECHNOLOGY REVIEW

MAY•JUNE 1999

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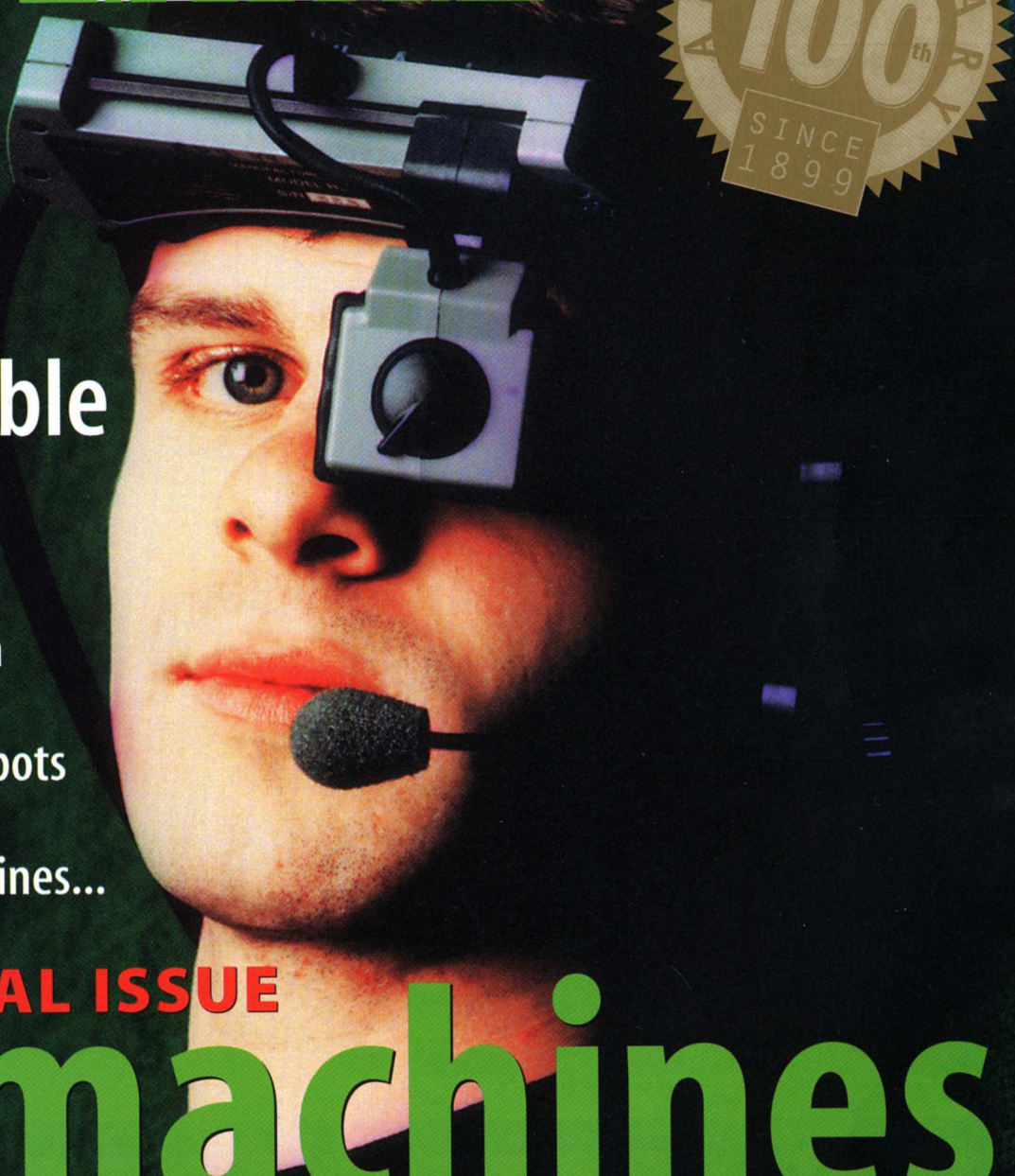

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SPECIAL ISSUE

Humachines

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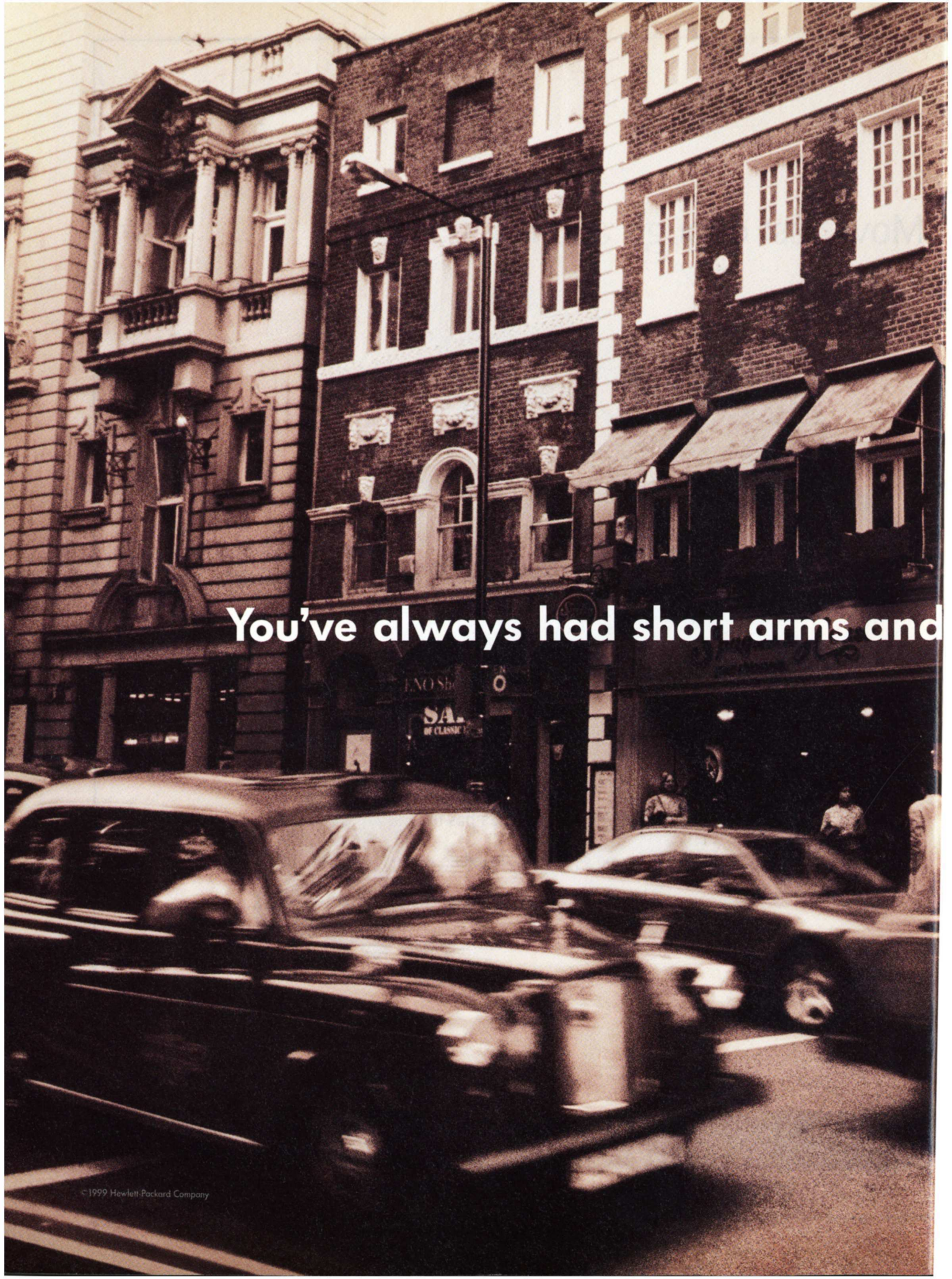
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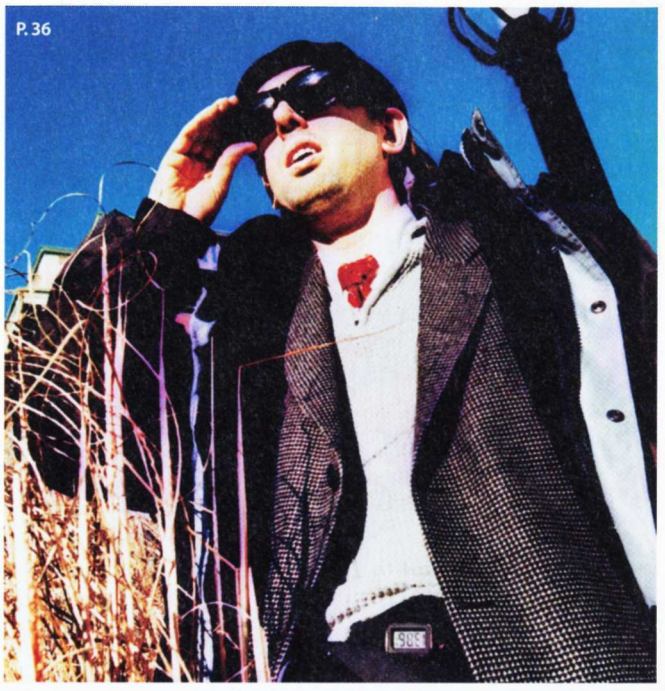
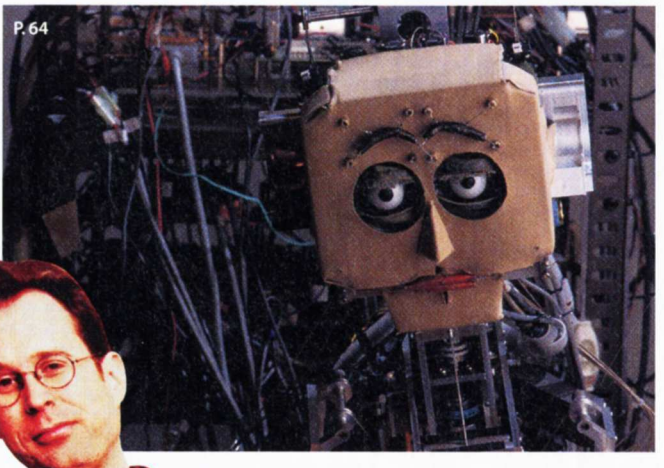
The next E. **E-services.**

Features

SPECIAL ISSUE: HUMACHINES





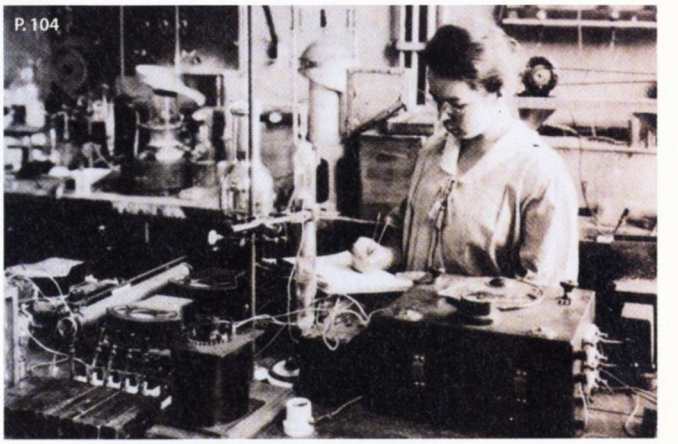
Cover photograph by Rick Chard

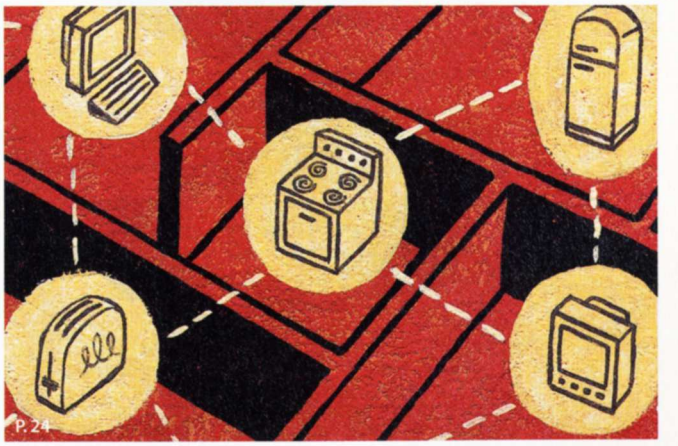
Departments

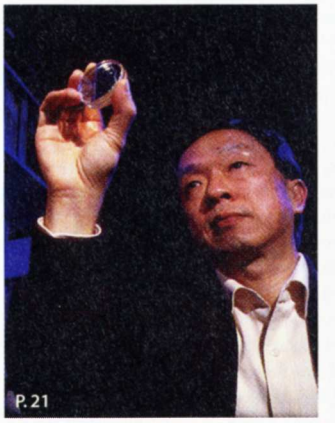

P. 21

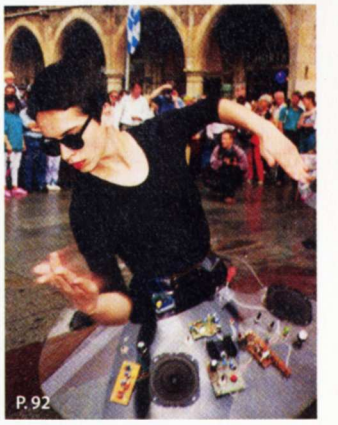
Culture Zone

Columns


P. 104


P. 24


P. 21


P. 92

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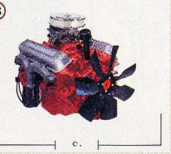
③ 

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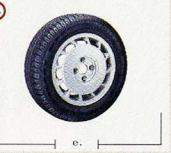
⑤ 

e.

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A few other products that have benefited from NASA technology.

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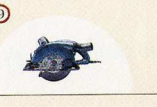
⑨ 

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INDEX

People and Organizations in Our Articles

PEOPLE

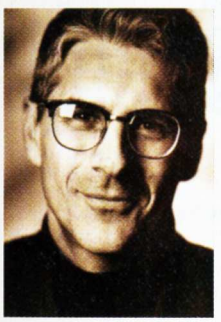
ORGANIZATIONS

Humachines

DON'T BE SURPRISED IF YOU DIDN'T RECOGNIZE THE TITLE OF THIS COLUMN. THE word isn't in dictionaries yet. But it may be soon. Or some other word like it, coined to describe the symbiosis that is currently developing between human beings and machines. *Humachines.* A few examples:

A Canadian teenager begins tinkering with imaging and computing systems that can be worn on his body. His first effort is a burdensome rig that blisters his feet when he wears it—and causes people to cross the street when they see him coming. Later he comes to MIT. Nicholas Negroponte, director of the Media Lab, recognizes the young man's inspiration and lets him earn a doctorate in "wearable computing." Today, Steve Mann, a professor at the University of Toronto, having worn computing gear of his own design virtually every day for the last 15 years, is hankering to assemble a community of human-machines, who will share perceptions and thoughts. "Cyborgs," he calls them, using a word from the early history of computing. We'd say *humachines.*

Second example: Harold Churchey, a blind man from Maryland whose retinas were destroyed by an untreatable disease called retinitis pigmentosa. Churchey participates in a series of experiments at Johns Hopkins aimed at creating an artificial retina: a silicon device that will transmute light into electrical signals and send them to the brain, where they can be interpreted as visual images. In the not-too-distant future, Churchey and many others like him may have artificial retinas implanted in their eyes, joining seamlessly with their biological nervous systems.



In the world of art, too, human beings and machines are becoming increasingly intimate. Consider another *humachine:* David Rokeby, a Canadian artist and self-educated computer tinkerer. Rokeby's artistic efforts are so thoroughly entwined with his video camera and Macintosh that it's impossible to tell where the artist leaves off and the technology begins. His dances, for example, are accompanied by a musical score that fits his movements like a glove—largely because it's created simultaneously by camera and computer as he moves.

These are all instances of human beings joining with or assuming the powers of the machine. But the phenomenon works the other way, too, as machines assume qualities we think of as human. The Japanese, for reasons that are rooted in their specific cultural history, are particularly receptive to the idea of warm and friendly robots—robots you wouldn't mind hugging or having as pets in place of a cat or dog. These androids are now coming out of many Japanese universities and corporate laboratories.

The blending of human and mechanical capabilities cannot be reversed. Machines are now in our bodies and minds—and we in theirs—far more firmly than ever before. This is an exciting prospect, because it extends our human powers into the world in new and wonderful ways. But what excites can also be frightening, because it blurs the boundary between us and our mechanical servants, raising the possibility of our being invaded and controlled in unforeseen and devious ways. How we respond to this paired fear and delight will constitute a large part of the human future. *Humachines.*

After reading this issue of *Technology Review,* you'll begin to see them everywhere. We already do.

—John Benditt

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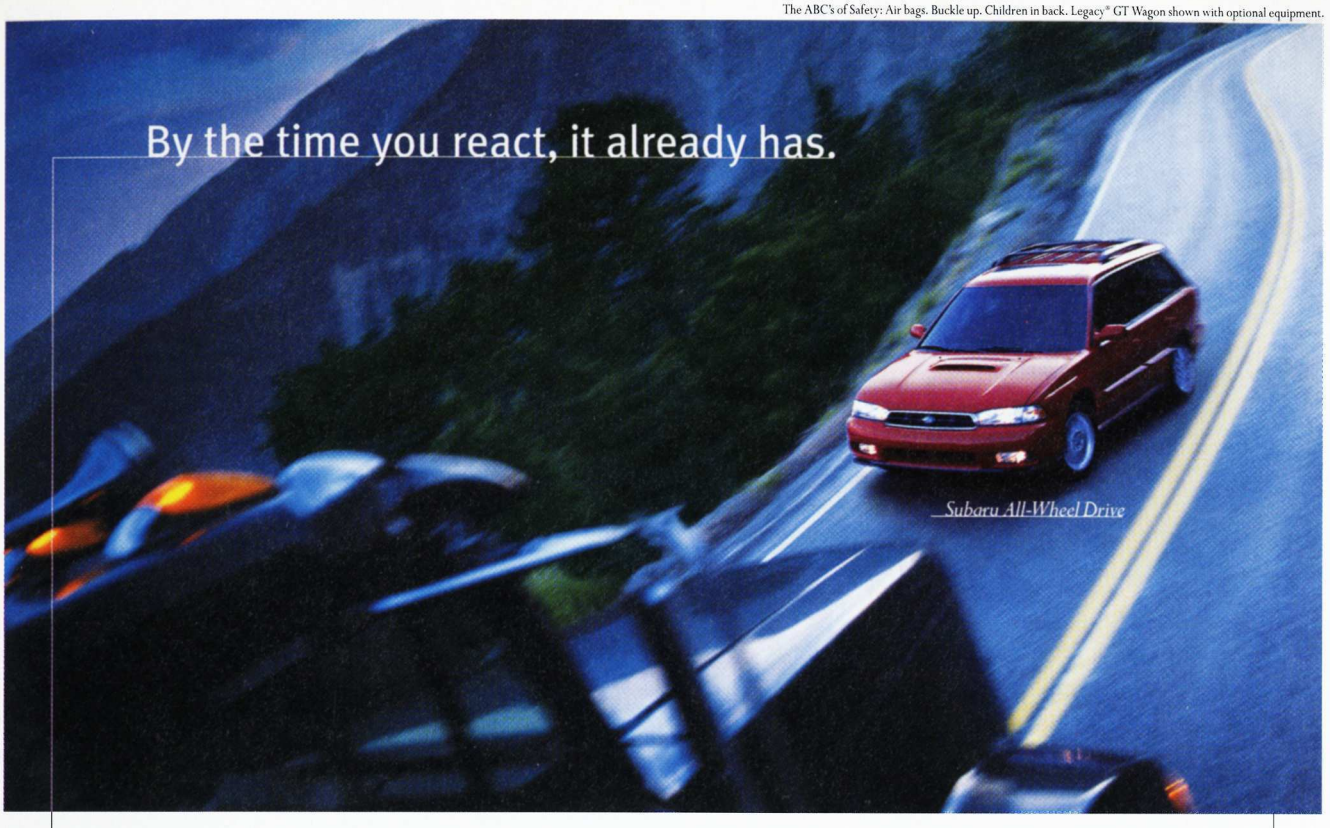

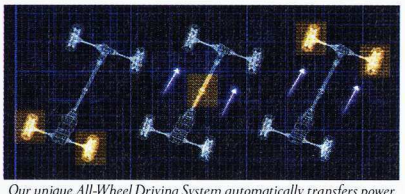

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SUBARU

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Once you start looking for them, humachines pop up everywhere. So we had a wealth of subject matter to choose from when we assigned the feature stories for this special issue of *TR* on human-machine symbiosis. The topics we picked range from instances of humanity literally merging with hardware to figurative explorations of the theme in art and music. In "Seeing is Believing" on page 44, **Victor Chase** tells the inside story of pioneering experiments that have laid the groundwork for restoring vision to the blind using electronic implants. Tracking down scientists and their human subjects, Chase's dogged reporting took him deep into the emerging field of artificial sense organs. During his 30-year career, Chase has covered energy, medicine and telecommunications for publications such as the Smithsonian Institution's *Air & Space* magazine and *Popular Mechanics*.


CHASE

For a story on Japan's android craze *TR* turned to **Bob Johnstone**, a journalist who earned unique insights into the Japanese innovation establishment during a 5-year stint as *New Scientist*'s Tokyo correspondent. (See *TR*'s review of his stereotype-shredding book *We Were Burning: Japanese Entrepreneurs and the Forging of the Electronic Age* in the March/April issue.) Johnstone, an alum of MIT's Knight Science Journalism Fellowship Program, now lives in Melbourne, Australia.


JOHNSTONE

To catch Japan's anthropomorphic machines on film, *TR* hitched a ride with award-winning lensman **Peter Menzel** on his globe-wide project to photograph advanced robots and their human creators. Now shooting in Germany, Menzel says roboticists in real estate-challenged Tokyo work in spaces so small that he could barely squeeze in his lighting equipment. Menzel's latest book is *Man Eating Bugs: The Art and Science of Eating Insects* (Material World), co-authored with his wife and collaborator Faith D'Aluisio.


MENZEL

The electronic tutu never showed, but dance critic **Merilyn Jackson** saw plenty of dancers doubling as lighting and audio engineers during four days at the International Dance and Technology Conference in Tempe, Ariz., last February. As Jackson notes in her review on page 92, "Dancing in the Fast Lane," the integration of dance with digital technology still has loose wires. Jackson splits her time between Phoenix and Philadelphia; her reviews appear regularly in *The Philadelphia Inquirer* and *The Phoenix New Times*.

In this issue's essay, "The Disembodied Photograph," celebrated media critic **A.D. Coleman** reflects on what the era of digital photography holds for art, journalism, forensics and eveningwear. Coleman says the age of 0's and 1's has affected the critic's work too: His intellectual aerie is now regularly invaded by incoming emails "from total strangers [seeking] on-the spot private (and uncompensated) critiques." For more Coleman, look for his book of essays *The Digital Evolution: Visual Communication in the Electronic Age* (Nazraeli Press) or visit his Internet newsletter *C: The Speed of Light* on the Web at www.nearbycafe.com.


COLEMAN

Also keep an eye out for *Architects of the Information Society* (MIT Press), *TR* contibuting writer **Simson Garfinkel**'s just-published history of MIT's Laboratory for Computer Science. In "Fountain of Ideas" on page 82, Garfinkel treats *TR* readers to LCS's best ideas and most successful spinoffs. TR

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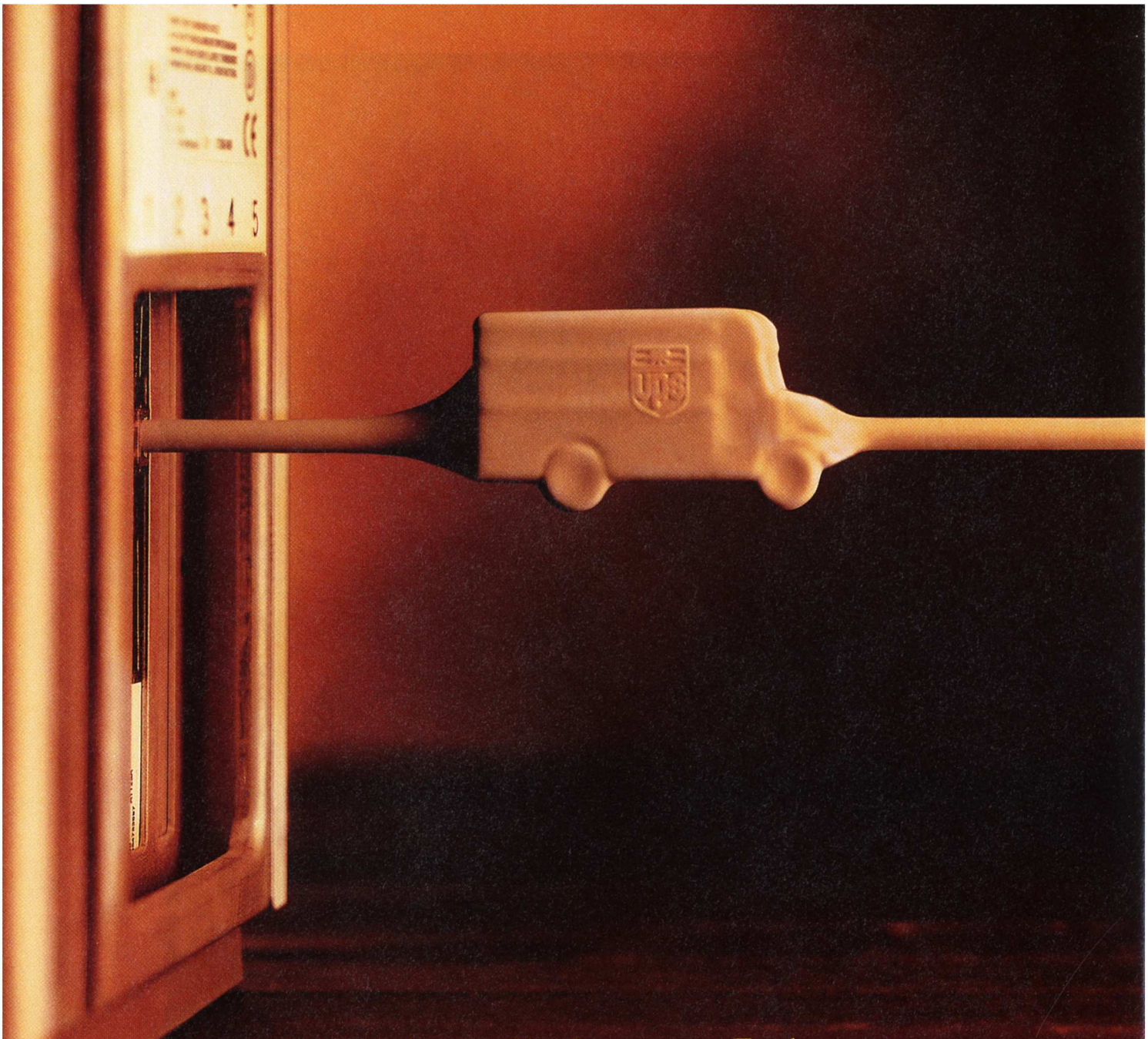

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Luddite Editor?

THE EDITOR'S NOTE ACCOMPANYING THE article "God's Eyes for Sale" evokes visions of Luddites revisiting the value of new technology in relation to societal and security concerns. Unfortunately, the editor, being unfamiliar with the nine-year history leading to the brink of launching commercial high-resolution satellites, makes an inappropriate and misdirected suggestion: He suggests the Clinton administration revisit this issue.

For the record, the U.S. government and U.S. industry worked aggressively and collectively, beginning in April 1990, to formulate a space commercialization policy that linked national security and economic interests. During the four years that led up to the Presidential Decision Directive 23 (PDD-23), signed by President Clinton in March 1994, bipartisan discussions involving the congressional and executive branches, the national security agencies and US industry were conducted.

Today, US industry is poised to launch one-meter imaging satellites. Space Imaging, Orbital Science, Earthwatch and others are all making substantial economic investments based on PDD-23 and the subsequent Department of Commerce one-meter licenses.

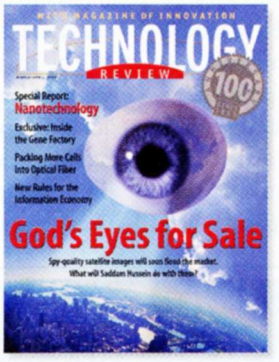
I suggest *Technology Review* stick to reviewing technology.

JOHN NEER
Vice President of Engineering
Space Imaging

YOUR ARTICLE ON COMMERCIAL HIGH-resolution satellite imagery is evidence of how history repeats itself. The security issues you raise echo the debate that took place when U.S. and Soviet spy satellites began photographing the world. Will commercial high-resolution satellite imagery be used to verify arms control and environmental agreements? History tells us the answer is yes. Will this same technology be used by "bad guys" for targeting purposes? It was used for these purposes in the past, so we should anticipate that it will be used for such purposes in the future.

We need not only to promote the beneficial consequences of this technology, but also to identify all possible ways this technology can be used to hurt others.

VIPIN GUPTA
Sandia National Laboratories
Livermore, CA



GOD'S EYES???!!! HAVE YOU taken leave of your senses? Do you have an infiltrator from Bob Jones University on your staff? You missed a great opportunity here. The title should have been: "What Santa Sees from His Sleigh." Not only is it alliterative, it also makes *exactly* the same degree of sense.

VICTORIA D. MCCOY
Glen Haven, CO

THE ARTICLE ON COMMERCIAL SPY satellites, while informative, presented needlessly alarmist attitudes offered by two academics at George Washington University. Any terrorist, miscreant or "rogue government" can target any major airport in the U.S. by purchasing any Airport/Facility Directory. These volumes of frequently updated Flight Information Publications are distributed for sale to pilots by the Dept. of Commerce, National Oceanic and Atmospheric Administration. They feature Airport Reference Points—the latitude and longitude of the plotted geographical center of the runways at all civil airports.

GEORGE BAILEY
S. Orange, NJ

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Nanofuror

CONGRATULATIONS ON YOUR REVIEW, "Nanotechnology: The Hope and the Hype." Your writers clearly distinguished hype from hard science and vision from reality. I was reminded of Richard Feynman's famous 1959 after-dinner talk, "There's Plenty of Room at the Bottom." Somehow, Feynman managed to foreshadow decades of advances in lithography, microelectronics, and information storage, continued progress in chemical synthesis, the linkage of biochemistry and information processing, and the emergence of tools to see and manipulate individual atoms. Of course he didn't get the details right, but I know that his vision influenced at least a few of the individuals who have made these things happen.

THOMAS N. THEIS
IBM Research Division
T.J. Watson Research Center
Yorktown Heights, NY

WHILE I AM HAPPY TO SEE THE INCREASing interest in nanotechnology, I was disappointed by your special report on this important subject. Mark Reed summarized one common thread in the articles when he said "There has been no experimental verification for any of [Eric] Drexler's ideas." Presumably, this includes the proposal to use self-replication to reduce manufacturing costs. The fact that the planet is covered by self-replicating systems is at odds with Reed's claim.

Self-replicating programmable molecular manufacturing systems, a.k.a. assemblers, are not living systems. This difference lets Reed argue that they have never before been built and therefore their feasibility has not been experimentally verified. Of course, this statement applies to anything we have not built. Reed has discovered the universal criticism. Proposals for a lunar landing in 1960? Heavier-then-air flight before the Wright brothers? Babbage's proposal to build a computer before 1850? No experimental verification. Case closed.

Those of us who have thought about molecular manufacturing and modeled the components that could be used in such systems have reached a conclusion: We should

be able to arrange atoms and molecules in most of the patterns consistent with natural law. Feynman reached the same conclusion in 1959 (see http://nano.xerox.com/nanotech/feynman.html). He, too, lacked experimental verification.

For a deeper analysis of some of the issues raised by *Technology Review*'s special report on nanotechnology, see http://www.foresight.org/hotnews/1999MITRev.html.

RALPH MERKLE
Foresight Institute
Sunnyvale, CA

I HAVE JUST CREATED A WEB SITE, CALLED Nanotechnology without Genies, which is my own attempt to sort out what's real and what isn't in nanotechnology. The URL: www.geniebusters.org. Anyone who thinks there must be something wrong with Eric Drexler's scenario, but who hasn't been able to say exactly what's wrong with it, should find something of interest here.

LYLE BURKHEAD
Los Angeles, CA

YOUR THREE ARTICLES PURPORTING TO BE a "special report on nanotechnology" were disappointing; their science and technology content was meager. I noted three paragraphs and three figures out of the three articles with technical content. Most of the subject matter dealt with personalities in the field and tidbits of work at various labs. But much was about possible applications, business-oriented fluff interspersed with clichés about how all this technology may affect the future of chip development and other applications. As I feared, your new format seems aimed more at business people and managers and less at engineering and scientific types, who are closer to what MIT is about.

DAVID SHONTING
Middletown, RI

Anti-anti-trust

YOUR Q&A WITH CARL SHAPIRO AND HAL Varian was very enlightening. I had always thought the sole reason for antitrust was to provide power and jobs to politicians, bureaucrats and economists, and payoffs to special interests and big campaign contributors. It never occurred to me that prosecuting successful companies was somehow good for me as a consumer. Can you believe that I even thought that companies that don't keep up with technology and don't give good value to their customers would lose market share!

W. ALAN BURRIS
Pittsford, NY

Why 2K?

I RECENTLY READ MICHAEL DERTOUZOS' "The People's Computer" column regarding the Y2K problem, and would like to offer another perspective.

The issue has never been one of lack of knowledge, it has been one of lack of appropriate and adequate response. Two factors are to blame. The first is the shortsighted nature of American business. American corporations are notorious for seeking short-term results and being slow to react to changes in the marketplace that can affect their bottom lines.

The second factor is IT management. Most mid-level and senior IT managers in the 1990s were people from the mainframe world who knew little or nothing about networked PCs and the Internet. They never made any attempt to replace

dated systems with new networks and Windows-based applications.

Yet such replacements would have addressed the larger problem at hand. Instead of funneling billions of dollars into patching COBOL systems, these people could have been far more proactive and saved millions by replacing dated systems, instead of trying to modernize and fix them.

Unfortunately, it is only recently that younger managers who grew up with local area networks and the Internet are being allowed to make management decisions that should have been made five years ago to address these problems. In many cases, it may be too late.

PETER T SZYMONIK
Regional Manager, Northeast
Romac Emerging Technologies
Manchester, CT

Benchmarks

REGARDING "THINK GLOBALLY, ACT DIGITALLY" in the March/April 1999 issue, I have a question. The statement was made that assigning one pixel to each square meter of the earth's surface would require over 1 petabyte, but it was not clear whether the author was talking of the entire surface of the globe, or merely the land surface. Which is it?

STUART GODWIN, JR.
Chestertown, MD

The editors respond: the petabyte estimate was made for land surface only.

I BELIEVE THE ION IMPLANTATION process has a tooling application not mentioned in the article "Ions on the Prize": printed circuit board drills. These drills are a major cost and quality factor in the industry. The drill ion implantation and resharpening process could be established as an outsource business used by the printed circuit board industry.

ROBERT CRUZ
Leominster, MA

Correction: The Reel Story

Apologies to frustrated film buffs who followed the incorrect Web address we provided for the Internet Movie Database in the March/April issue ("Net Nuggets," p. 94). The correct URL is www.imdb.com—and it's still worth a visit.

A Death in the Family

One of Technology Review*'s familiar voices has been stilled. Bennett Harrison, whose column "The Economic Perspective" graced our pages from 1988 to 1998, died in January of cancer; he was 56. Ben joined the* TR *team while a professor in MIT's Department of Urban Studies and Planning, and stayed with us after leaving Cambridge for Carnegie Mellon University. He was most recently a professor of urban political economy at the New School for Social Research in New York. Ben's trenchant columns analyzed the role of technology in economic change. Although often critical of the status quo, Ben believed deeply in positive change; cynicism was not in his repertoire. He was co-author of several books that helped set the terms of economic policy debate—from 1983's* The Deindustrialization of America *to 1988's* The Great U-Turn *to 1994's* Lean and Mean. *We remember Ben not only for his prescient thinking and eye-opening essays but also for his intellectual passion and the camaraderie he engendered among all who worked with him.*


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We see the future of communications (and it's looking good).

Some will tell you the future
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one kind of network.
We see a bigger picture than that.
(We're optimists.)
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service to make it all work.
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communications work.™

Shrink Big

Chemical plants are immense, with miles of distillation columns and reaction chambers the size of small buildings. A team of chemical engineers and microfabrication experts at MIT's Microsystems Technology Laboratories (MTL) has shrunken all that down to a "factory-on-a-chip" capable of spewing out commercial quantities of chemicals.

The MIT team, headed by chemical engineer Klavs Jensen and MTL director Martin Schmidt, has made milliliter quantities of chemicals, carrying out common reactions such as the oxidation of ammonia to form nitric oxide. The group is collaborating with DuPont to interconnect these microfactories; a cabinet stuffed with thousands of these chips could, Jensen estimates, produce several tons of a chemical per year. That would be plenty for many processes requiring small amounts of high-purity chemical.

CPR to Go

CARDIOLOGIC SYSTEMS

A portable version is on the way to replace the hospital version shown.

Cardiac arrest can strike without warning: That's one reason why thousands of volunteers have learned cardiopulmonary resuscitation (CPR). Although the chest-pumping technique moves air into the lungs and blood through the body, it is difficult to perform correctly; a few minutes of lifesaving exertion can exhaust even the burliest paramedic. Overall, only 15 percent of cardiac arrest victims survive.

CardioLogic Systems, a tiny research outfit in Baltimore, Md., is lab-testing a portable, inflatable vest that could provide a safer, easier way to do CPR. The nylon vest wraps around the victim like a big blood pressure cuff; a battery-powered pump drives 10 liters of air into the vest every second. Cardiologics faces competition in the portable-CPR niche from several other R&D outfits. Before the devices become a common sight at poolsides and in ambulances, however, developers must prove they outperform manual CPR in clinical tests.

Lit-up Lenses

ENLIGHTENED TECHNOLOGIES ASSOCIATES

Lighting the way to bliss.

Spring has lengthened the days in the Northern Hemisphere, but south of the equator, winter—and the attendant gloom—will soon arrive. In Buenos Aires and Cape Town, sufferers from seasonal affective disorder (SAD) are feeling the lethargy, food cravings and depression that result from their brains' failure to shut down production of the nighttime hormone melatonin. There is a physician-tested remedy for the "winter blues": an hour of exposure to bright light each morning. Many SAD patients use $300 tabletop light boxes. But they may eventually may be able to get their dose of summer light on the subway or at work. Enlightened Technologies Associates, a Fairfax, Va.-based startup, has rigged a pair of glasses with a battery, LED and fiber optics to deliver light directly into the pupil. Because the light enters at an angle, the user still sees normally. Tests are under way for treating SAD, sleep disorders (especially among the elderly) and jet lag.

Of Mice and Men

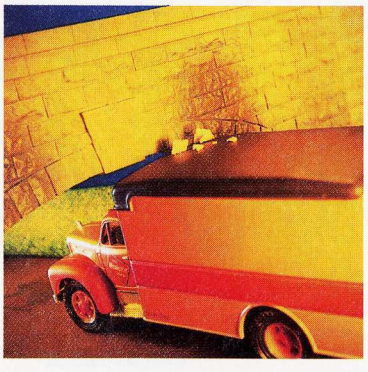
About one million Americans carry the hepatitis B virus (HBV) which can lead to liver cancer. But the search for treatments has been stymied by the lack of a suitable animal for testing new drugs. Rodents don't get HBV, and chimpanzees, which do, are expensive.

PHOTO DISC

XTL Biopharmacueticals in Rehovot, Israel, has come up with a solution by creating a mouse with a bit of human liver inside it. XTL's recipe: destroy the immune system of a normal mouse with gamma rays. Next, transplant a peppercorn-sized fragment of HBV-infected human liver, along with bone marrow from an immune-deficient mouse. XTL calls the resulting creature a "trimera" because it has components of three different animals. Since the mouse's weak immune system doesn't reject the human cells, there is time to test the effects of anti-viral drugs. XTL hopes to develop trimera models for cancer.

Blimey Bash

Britain has two cultural icons on a collision course: Twice a day, on average, high-profile vehicles such as double-decker buses smash into the country's ubiquitous low-hanging railroad bridges. Each collision interrupts train service while engineers determine whether the bridge is still sturdy. It's a time-consuming process that annoys passengers and costs Railtrack, the nation's rail authority, the equivalent of about $8 million a year.

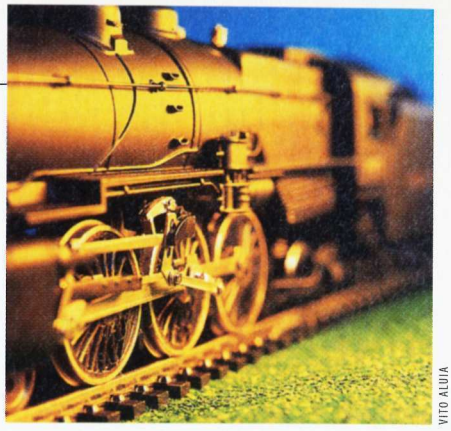


VITO ALUIA

Enter the Bridge Bash Monitor. Developed by AEA Technology in Oxfordshire, England, the system uses a PC and video camera. Strain and vibration sensors are positioned on the bridge and connected to the PC; in an accident, the system alerts a control center, where experts check the damage. AEA installed the first monitors, which cost roughly $20,000 for each side of a bridge, this spring. It claims the system could also monitor river bridges that are vulnerable to wayward boats.

Robocasting

Although it's often valuable to have ceramics and metals in the same device, joining them together is difficult—differences in heat expansion often cause cracking where the materials meet. One possible solution: Moving gradually from one material to another to spread the stress evenly, and yield a more stable joint. A new rapid prototyping technique developed at Sandia National Laboratories in Albuquerque, N.M., called robocasting, builds up hybrid parts by dispensing small amounts of a ceramic slurry. By mixing more nonceramic material into the slurry over time, Sandia's robot makes a graded part. Engineer Joe Cesarano says the robocast pieces, which can be created in less than 24 hours, have an additional advantage: They're denser than ceramic parts made by other rapid prototyping methods. The metal-ceramic parts would be particularly useful in engines that operate at very high temperatures, Cesarano says.



VITO ALUIA

Laser Glazer

A train needs friction between its wheels and the rail's upper surface in order to move, but friction between the wheel and the sides of the rails is a different matter. Over time, the stress from this friction, especially as trains go around curves, can cause rails to crack; sometimes train wheels even climb over the sides of tracks and derail. The railroad industry combats this problem by applying lubricant to rails, but it's far from a perfect solution: The environmentally unfriendly stuff seeps into the ground and sometimes spreads to the rail tops, making them slippery. Researchers at Argonne National Laboratory in Argonne, Ill., are using a laser to rapidly melt and re-solidify the steel on the side of the rail. This "glazing" creates a slippery surface that is also more durable. Although research is still in its early stages, principal investigator Ron DiMelfi estimates that laser glazing could save the U.S. railroad industry $40 million per year on fuel and $16 million per year on rail replacements.

Sight Saver

DAVID HUNTER

Hunter checks eye alignment.

As many as 5 percent of children suffer from amblyopia, or "lazy eye," which causes an otherwise normal eye to lose proper vision. Often the result of a misalignment of the eyes, lazy eye is treatable if caught early—but diagnosis is trickier in children too young to read an eye chart. So Johns Hopkins pediatric ophthalmologist David Hunter and his colleagues have built a device to check eye alignment automatically.

The device, still in early testing, shines a polarized infrared beam into a patient's eyes and analyzes the light coming back to detectors. When the beam reflects off the fovea—a small, specialized area of the retina responsible for high-acuity vision—it has a characteristic signature. By looking for this signature, Hunter says, the device can tell when an eye that should be aimed straight at the light is more than one degree off the mark. Hunter's team is working on a second-generation prototype and looking for a commercial partner to help develop the device.

Mightier Pen

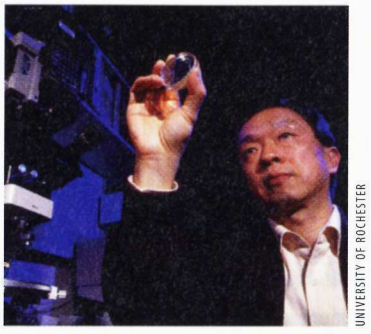
BRITISH TELECOM

Even digerati spend some time unplugged, jotting notes on paper. British Telecom has demonstrated a pen that converts scribbling motion into digital characters. Unlike the stylus found on personal digital assistants, "Smart Quill" uses ink and writes on paper. A couple of built-in accelerometers record your hieroglyphics. Back at the office, dip Smart Quill into an electronic "inkwell" that delivers the jottings to your PC. The computer interprets the motion data as text.

A prototype correctly interprets writing 95 percent of the time, says project manager John Collins at British Telecom Laboratories in Ipswich, England; but the goal is "high 90s." Collins says British Telecom is looking for a partner to bring Smart Quill to market.

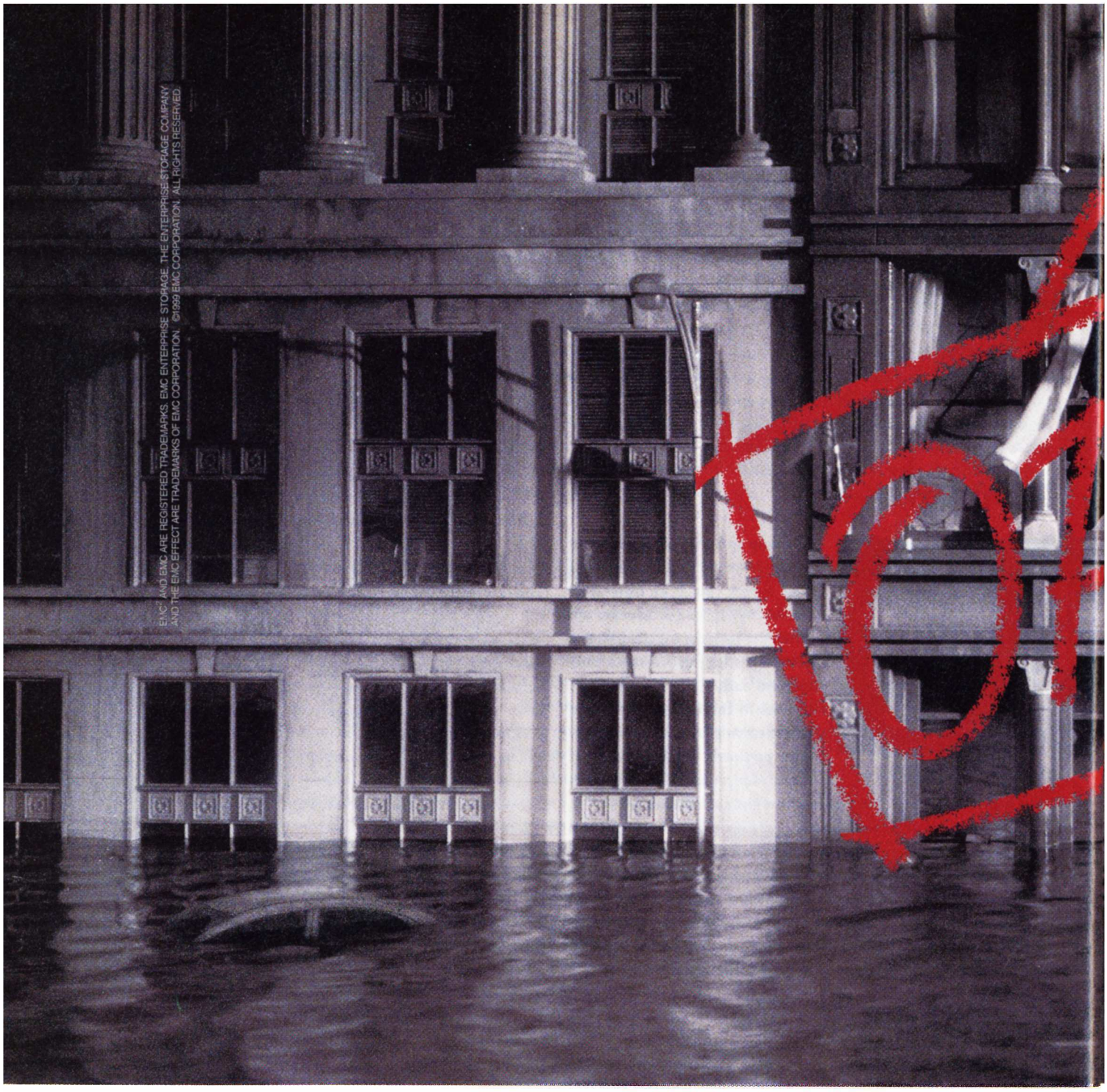
Virtuous Circle

Looks aren't everything. But in the world of computing, as elsewhere, they mean a lot. Your laptop spends much of its power on its pretty graphic screen display. One reason: The light produced to illuminate a conventional flat-panel display has to be polarized, which means stripping away more than half of the light—the part that's polarized in the wrong direction—and throwing it away. University of Rochester researchers are developing a new class of materials called liquid crystal glass that, when hit by ultraviolet light, emit circularly polarized light with 99 percent efficiency. Circularly polarized light (in which the direction of polarization constantly rotates) makes for brighter screens with better contrast than current displays. Avoiding the need to discard half the light generated would cut power consumption and thus extend battery life; this efficiency might also enable such technologies as 3-D displays. Kaiser Electronics in San Jose, Calif., is exploring display and eyewear applications of the materials.



UNIVERSITY OF ROCHESTER

Class of the glass.



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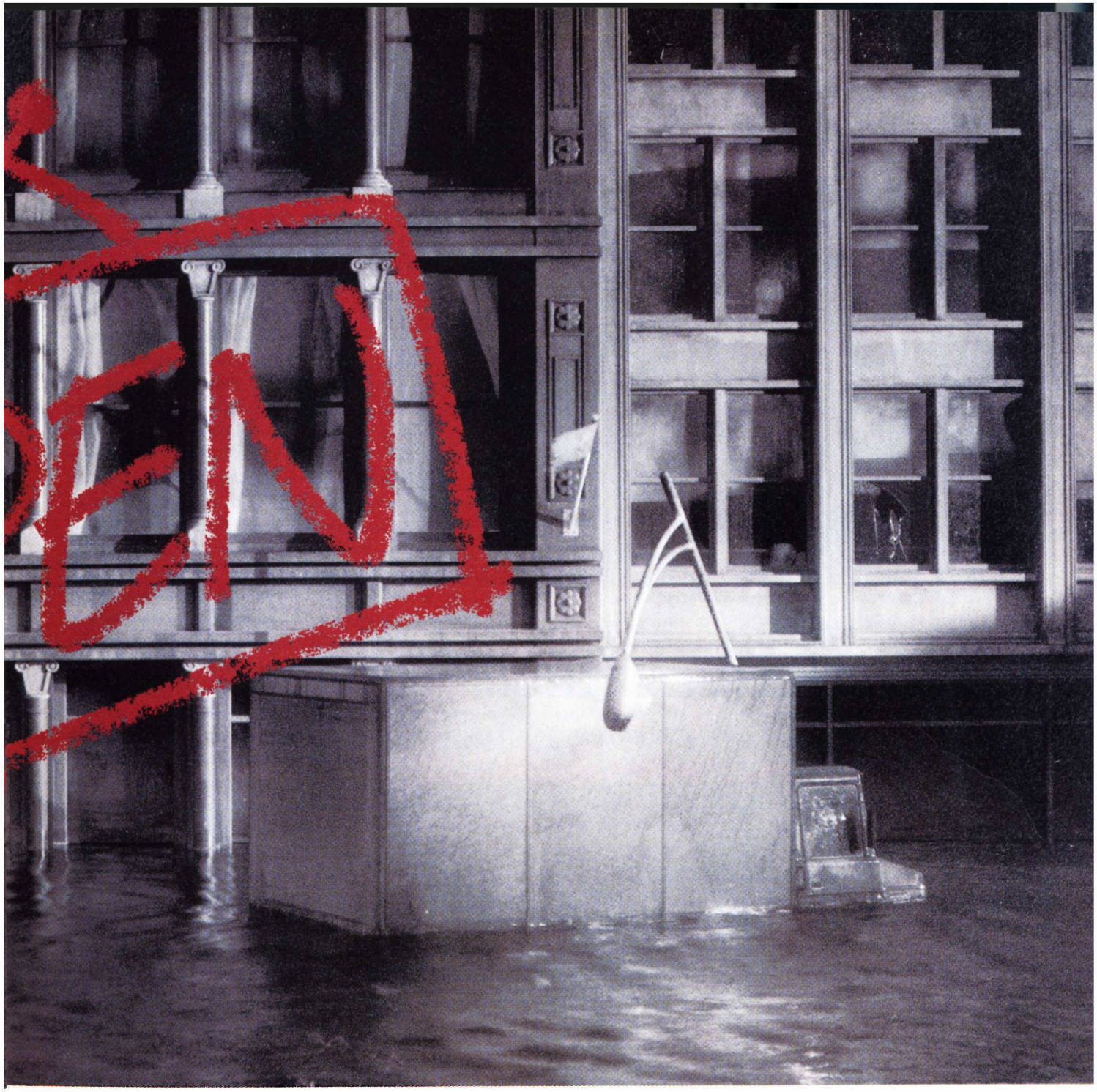

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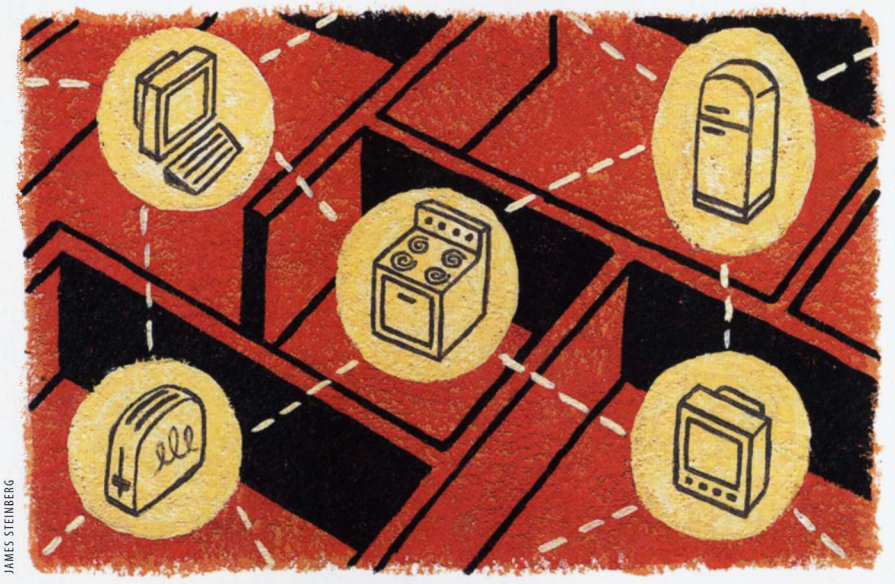


JAMES STEINBERG

VENTURE CAPITAL

Network the Valley!

Panasonic creates a nursery for fresh ideas

SILICON VALLEY HAS A WELL-DESERVED reputation for having a Midas touch when it comes to turning technology into money. Much of that success is credited to an entrepreneurial culture that fosters startup companies. Hoping some of the magic rubs off, Panasonic plans to open a 20,000-square-foot incubator next month in Cupertino, Calif., that will house some 15 to 20 startups. To go along with its Panasonic Digital Concepts Center, the company will also set up a $50 million venture capital fund to support the firms.

The incubator is the result of a decision made two years ago, when Panasonic, the consumer electronics arm of Japan's Matsushita Electric, decided it needed to get a grip on the much-heralded "convergence" of TVs, personal computers and telephones—all of which Panasonic manufactures. The company's first thought, says Paul Liao, Matsushita's chief technology officer in the United States, was to build a corporate R&D center in Silicon Valley. But, says Liao, "we realized that the Valley is not so much about R&D as it is about venture startups. They are the new way of doing R&D."

Investing venture capital in startup companies in Silicon Valley is not unusual for big electronics firms. Last year, Lucent Technologies created a $100 million fund, and MCI WorldCom established a $500 million investment fund. Panasonic, however, appears to be the first to also build a facility to house early-stage startup companies.

Incubators are celebrated hotbeds of intensity and innovation—communal workspaces where geeks burn the midnight oil and entrepreneurs sleep under their desks dreaming of an IPO. Charles Wu, the Digital Concepts Center's director, says that's exactly what Panasonic is hoping for. Matsushita engineers and managers will be able to visit this microcosm of Silicon Valley culture "and act as a bridge to factories and divisions in Japan." Most important, says Wu, Panasonic will get an early peek at home networking software.

Liao points out that appliances such as TVs, PCs and DVD (digital versatile disk) players, now "all have the same basic technology inside." Namely, microprocessors. The question for Panasonic is what happens when all these devices start talking to one another.

The incubator's first prospective tenant, InterActual, is developing software that adds an interface to DVD movies that allows a consumer to "play with" the movie on a computer DVD-ROM optical disk drive (a new generation optical disk drive). The idea is that after watching a DVD, you'll slip it into your PC where you can read the screenplay, play video games, and (thanks to Panasonic's investment in the startup) find Internet links to Panasonic's online shopping site. Now that's convergence—of a very commercial kind.

—Antonio Regalado

FREE SOFTWARE

Linux Gets a Desktop

The Free Software Foundation has released software that puts a friendly face on the Linux computer operating system, the flagship of the "open source" software movement. The new software, GNOME (pronounced guh-NOME), is the culmination of a two-year effort by volunteer programmers around the world to make Linux accessible to everyday computer users *(see "Programs to the People," TR January/February 1999).*

Although hailed in some quarters as a Windows alternative that could end Microsoft's operating system monopoly, Linux has so far gained only a limited following. One reason: its demand that users learn arcane commands. GNOME could change that by providing Linux with a graphical, point-and-click interface that users can customize as they choose—giving it a Windows feel, or a Mac feel, or something completely different.

Red Hat, the leading Linux distributor, will include GNOME in its next release of the system. GNOME is also available for free downloading at www.gnome.org.

—Herb Brody

MATERIALS SCIENCE

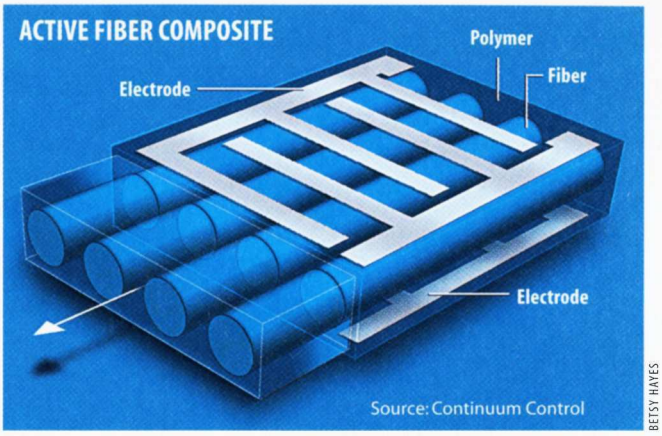
Getting Active

New ceramics: smarter, tougher

"Smart materials" are already a big hit in sports. In baseball, for instance, new aluminum bats can now quiet the "bees" a player feels when hitting a ball off the handle. Likewise, smart skis can damp vibrations as needed. The "active" part of these sporting goods is a credit-card-sized wafer that uses quirky but well-studied materials called piezoelectrics. These compounds convert mechanical stresses, such as vibrations, into an electric signal (which can be harmlessly shunted), or, conversely, change shape or size in response to electricity.

But what if researchers could find ways to make the entire product active, rather than just a discrete embedded device? That could mean smart helicopter rotors or airplane wings that twist on command, changing shapes to reduce vibrations and noise. Key to that is finding active materials that are highly responsive and yet tough enough to form structural parts.

Researchers may have come a step closer to achieving that, as several groups of materials scientists, including ones at Pennsylvania State University and MIT, have identified "single-crystal" piezoelectric ceramics that are far more active than conventional materials. The MIT group, headed by Yet-Ming Chiang, a professor of materials science, and Nesbitt Hagood, director of the Institute's Active Materials and Structures Lab, has now made novel single-crystal piezoceramics that can be easily made into fibers—a critical step to fabricating active composites that could be used to make entire structures smart.



New piezoceramics could make smart composites, developed at MIT, more practical and responsive. In the active composites, piezo fibers are aligned in a polymer matrix; an electric signal triggers an extension of the fibers.

Each type of the single-crystal materials has advantages. The MIT piezoceramics do not contain lead, which means they are less toxic and could be used in biological applications. The Penn State materials are more responsive but are lead-based and have not been made into fibers.

Nesbitt and his co-workers first developed active fiber composites several years ago using conventional piezo materials. The single-crystal piezos, however, could make the composites far cheaper and more practical, says Aaron Bent, founder of Continuum Control, a Cambridge, Mass.-based startup trying to commercialize the composites.

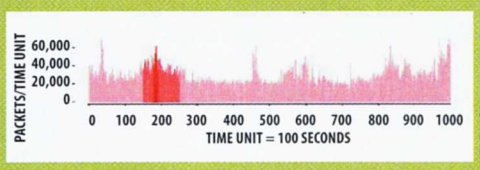
The MIT scientists hope to make an active fiber composite using the single-crystal piezoceramics within 18 months. **—David Rotman**

INFORMATION SCIENCE

The Fractal Net

You're downloading a file, or calling up a Web page. Suddenly, the cyberworld goes into suspended animation.

Why can't the Internet provide more consistent service? One reason is a lack of insight into the overall pattern of traffic on the Internet. Now, researchers at AT&T Laboratories have come up with some surprising answers to what's going on.



The Internet's erratic traffic pattern over roughly a day.

If you look at a plot of traffic through a network point over a minute, the trace will fluctuate wildly from one fraction of a second to another—an expected result. Now look at a day broken up in units of 100 seconds. On a voice network, the curve flattens out; instantaneous variations cancel each other out. But on the Internet, the AT&T researchers found the pattern of traffic had the same "bursty" character over long time periods as over short ones.

Such "self-similarity"—described by a type of mathematics known as fractal geometry—occurs often in nature. A coastline, for instance, has the same jagged appearance on a large scale as on a small one. According to Robert Calderbank, vice president for information sciences at AT&T Labs, the Net's self-similarity stems from the way people use it. Lengths of Internet sessions range over a span of 6 to 7 orders of magnitude. As a result, the flow of data on the Net resembles the mathematically complex phenomenon of turbulence.

This knowledge is allowing network engineers and service providers to rework the rules of thumb that they have used for 70 years in designing the telephone system, Calderbank says. Routers that incorporate the more sophisticated—and accurate—traffic algorithms should help data move through the Internet with fewer of those finger-drumming delays.

—Herb Brody

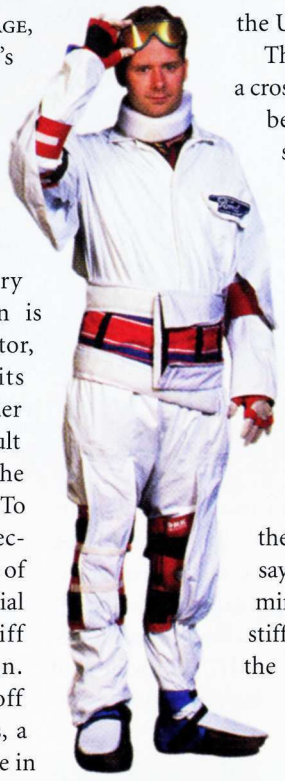
AUTOMOTIVE DESIGN

Suiting Up for the Golden Age 500

Ford's engineers try feeling old—to design a better car

FOR PEOPLE OF A CERTAIN AGE, it's obvious that today's automobiles are designed for a young and agile customer; even climbing in and out of a car can be a chore.

That isn't necessarily good marketing in a country whose Boomer population is rapidly aging. So, Ford Motor, for one, is encouraging its designers to think about older customers. But that's a difficult assignment when many of the designers are in their 30s. To give them a different perspective, Ford has outfitted some of their design team with a special "age suit," to simulate stiff joints and declining vision. The automaker will show off the results in its new Focus, a compact car that goes on sale in the United States this fall.



FORD MOTOR CO.

The 7-pound age suit looks like a cross between a karate outfit and beekeeper's garb. Braces that strap on with Velcro restrict the motion of every joint, from ankles to neck, by about 25 percent, says Fred Lupton, a 32-year-old Ford ergonomics engineer. A pair of foggy goggles, designed to simulate cataracts and the yellowing of the lens, completes the gear.

Just getting into the suit puts the designer in the right mood, says Lupton. "It takes about five minutes to suit up. You feel very stiff." The last piece to go on is the neck brace, but "once you have your elbows and wrists strapped in, you can't get it on yourself."

The cumbersome suit spurred the designers to make Focus easier to get in and out of. Ease of entry is facilitated by the high top of the door. The seat is also higher relative to both the ground and the car's floor than those in other compact cars, so that the driver can sit down instead of plopping down.

Besides the joint restrictors, the age suit includes latex gloves to dull the sense of touch. As a result, designers realized the Focus needed large, easy-to-feel control buttons. Trunk release latches, normally located on the floor next to the front seat, are next to the speedometer, reducing the need to bend.

Ford's efforts have drawn kudos from some safety researchers. Matthew Rizzo, a professor of neurology at the University of Iowa's College of Medicine, studies automobile accidents involving people with advanced age and cognitive impairment. Says Rizzo, "My hat's off to Ford."

—David Holzman

COMMUNICATIONS

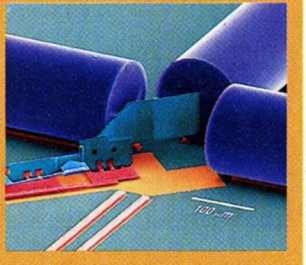
Optical Prime Time

As the load on communications systems multiplies, optical networks must become far more complex and interconnected. To fully optimize the flow of information along these networks, engineers need flexible and inexpensive ways to route the light. But at least one roadblock stands in the way: the lack of cheap, small, simple switches to direct the light. To help ease the congestion, scientists at Lucent Technologies' Bell Labs have built a tiny optical switch that works like a seesaw.

"It's basically a mechanical shutter" measuring about 100 micrometers across (about one-tenth the width of a human hair), says David Bishop, head of Bell Labs' microstructure physics research. The micro seesaw is made of a pivoting bar with a gold-plated mirror at one end and an electrode at the other. The mirror is positioned between optical fibers. When the switch is off, the mirror rests below the fibers, allowing light to flow between them. When a voltage is applied to the electrode, it's pulled down, swinging the mirror up between the optical fibers—and redirecting the light.

The switch is meant to be far smaller and cheaper than today's technology. Existing devices based on lithium niobate crystals are fast but are also extremely expensive, costing roughly $1000 apiece; mechanical switches made of lenses and motors can also be used but are about the size of a pack of cigarettes, making them awkward as optical networks are miniaturized.

Lucent's tiny switches, says Bishop, could be orders of magnitude cheaper than these devices, because large numbers can be made using the silicon technology used to fabricate integrated circuits. "This changes your notions of how you use optical switches and where you put them," says Bishop.



LUCENT TECHNOLOGIES

Bell Labs' switch at the intersection of optical fibers.

Bishop points to potential use of the devices as tools for adding or dropping specific wavelengths of light in optical networks and as switches that reconfigure networks on demand. And, says Bishop, the micro switches could help facilitate the use of fiber optics in household and desktop applications—uses that require cheap and simple ways to route light.

Bishop says Lucent expects to commercialize the new switches "shortly." The switches, he says, are now "ready for prime time."

—David Rotman

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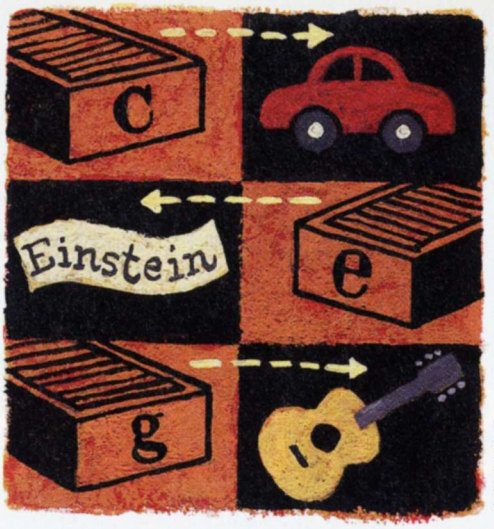
INTERNET

Generation Next on the Web

Improved protocol will aid online services



JAMES STEINBERG

THE WEB IS A HOUSE THAT WAS OCCUpied while still being built. And much of the plumbing and wiring was thrown together to meet immediate needs—with little thought to the long term. But if the Web is going to become comfortably habitable, it will need a refurbishing at its core.

Fortunately for all of us who are now living there, just such a replumbing is in the works. The initiative, by a working group of the MIT-based World Wide Web Consortium (W3C) *(see "The Web's Unelected Government," TR November/December 1998)*, goes by a daunting set of initials, HTTP-ng. That mouthful translates into the next generation ("ng") of the hypertext transfer protocol (HTTP). Just like plumbing, HTTP brings and carries away: uploading and retrieving documents, and embedding hyper-links. And while the new protocol won't directly change the look and feel of the Web for most casual surfers, the behind-the-scenes refinements will create standards to better support the proliferation of new online services for the Internet.

The version of HTTP now in use (1.1) is changed little from the original that was patched together willy-nilly as the Web was constructed during the early 1990s. In the meantime, however, millions of people and companies have moved in and concocted all manner of new services and features for the Web. "There are about 42 different applications using the Web apart from the basic act of fetching a page," says Bill Janssen of Xerox's Palo Alto Research Center, a member of the HTTP-ng working group.

Take, for instance, a rapidly growing phenomenon: online auctions *(see "Radio Daze," TR November/December 1998)*. The instant notification of bids to all participants requires operations not built into first-generation HTTP. "There are hundreds of ways" to improvise on HTTP to make auctions work, says Janssen, and most online auctioneers try several before settling on one. HTTP-ng would put in place standards that would make it much easier for Web sites to offer such services. Design of a new Web service, says Janssen, "should not require 20 geniuses working for three years."

A key goal of HTTP-ng is to make the Web more hospitable to automated "agents" that have been developed at MIT and elsewhere to seek out information and conduct transactions on behalf of a human user, says Henrik Frystyk Nielsen, the HTTP-ng activity leader at the W3C. The existing HTTP falls short, he says, partly because it lacks "semantic understanding" of the information on the Web page. A document on the Web may include the names of many people, but provides no clue to indicate which is the author—and searching bogs down as a result. In contrast, HTTP-ng will provide a consistent framework that can be utilized by new software applications that require some machine "knowledge" of a site's contents. It will be more like an orderly and navigable library.

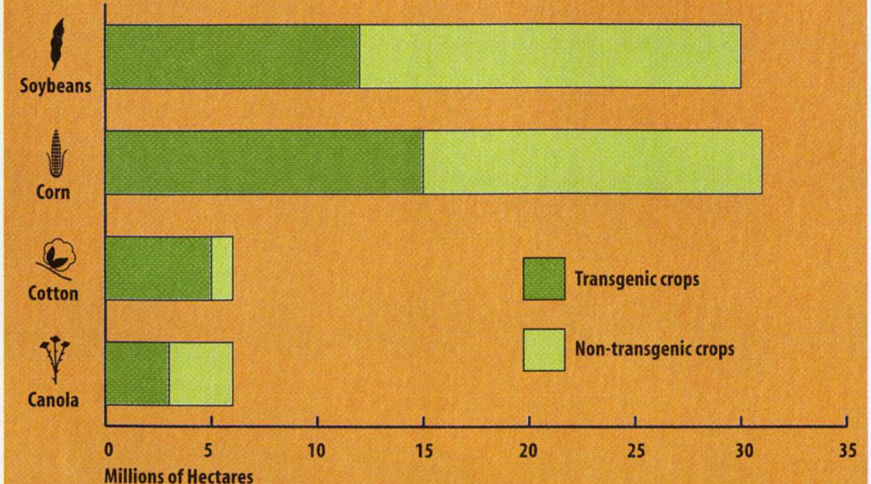
The new protocol is still being tested. Nielsen says that W3C intends to implement the changes gradually over a period of a couple of years, as part of an effort coordinated with the Internet Engineering Task Force—the group that looks after the underlying technical standards on which the Web runs. Once the kinks are worked out, though, the World Wide Web may finally prove comfortable for long-term occupancy.

—Herb Brody

AGRICULTURE

Biotech in Full Flower

This spring, as you drive past that familiar field of corn, you may be seeing a little more than meets the eye: an agricultural revolution in progress. Only three years after the first large-scale U.S. plantings of genetically engineered corn, chances are now almost 50-50 that those plants are of high-tech origin. Below is the projected planting of transgenic crops in the United States and Canada in 1999.



Source: The Bowditch Group

HEALTH CARE

Surf Your Prognosis!

MODERN HOSPITALS HAVE ADOPTED numerous high-tech tools, from advanced imaging instruments to robotic surgical aids. But when it comes to managing and sharing information, most facilities are fairly Dickensian. Next January, University of California, Los Angeles (UCLA) plans to begin construction on a medical center that could change all that; exchanging paper and film for 1s and 0s, UCLA Medical Center is investing $100 million to make its new hospital essentially all-digital.

To realize that goal, UCLA Medical Center's senior associate director/chief information officer J. Michael McCoy and his co-workers are developing a Java-

UCLA MEDICAL CENTER

enabled, Intranet-based browser that can integrate information from multiple clinical systems. Using in-room Web-TVs, patients will be able to go online to track treatment plans, communicate with medical staff, review their charts—or select a dinner entree.

For their part, health care providers will use Intranet-linked personal palm devices to check patients' latest test results, input vital signs, order medications, and perform other quick transactions. They'll also rely on radio-linked, flat-paneled mobile displays to review more detailed medical information.

Going digital poses difficult challenges for the hospital's information systems experts. And it's not cheap.

But if all goes well, UCLA hopes eventually to recoup its investment through more efficient patient care and hospital inventory management. For the patient, it could mean finally being on the inside when it comes to all those critical records.

—Mark Dwortzan

"European Air War's outstanding gameplay and wealth of features make it the current leader of the WWII simulation crop" *-PC Gamer, 89%, Editor's Choice Award*

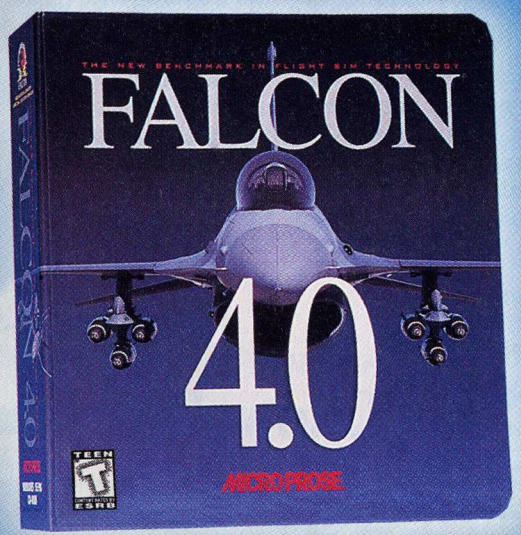
"This World War II simulation captured the feeling of being in a living, unpredictable combat environment better than any other sim released this past year" *-Computer Gaming World, 4 stars*

"European Air War succeeds at providing the experience that makes arm-chair fighter pilots believe they're truly leaving their mundane surroundings behind" *-Gamespot*

RACKING UP

"No previous sim covers so many different weapons and so many tasks in detail... it's all here and it's all beautifully executed" *-PC Gamer, 95%, Editor's Choice Award*

"Falcon 4.0 is the deepest, most complex air combat sim yet... The campaign also creates the greatest sense of playing a small but important part of a huge battle" *-PC Gamer*



"Thoughtful gameplay design and the effort to bring players a sense of the true fighter pilot's experience can be felt throughout the game" *-Computer Games Strategy Plus*


EUROPEAN
AIR WAR
30 FLYABLE PLANES!
MICROPROSE
"European Air War combined huge dog fights, a great campaign system and realistic physics to make a game that was very hard to put down"
-IGN PC.com, Sim of the Year
"The care and attention to detail that went into every aspect of European Air War, from the hefty manual to the bomber nose art, represents a serious achievement"
-CNET GameCenter
THE KILLS!
"Bottom line: this sets the new standard in flight sims"
-Washington Post
"Falcon 4.0 is an incredibly detailed simulation that in many ways exceeds training systems in military use."
-Computer Gaming World
PC GAMER
ANNUAL AWARDS
BEST SIMULATION
1999
GAMERS CHOICE AWARD
PREMIER FINALIST
1999
FlightSim.com
HASBRO Interactive
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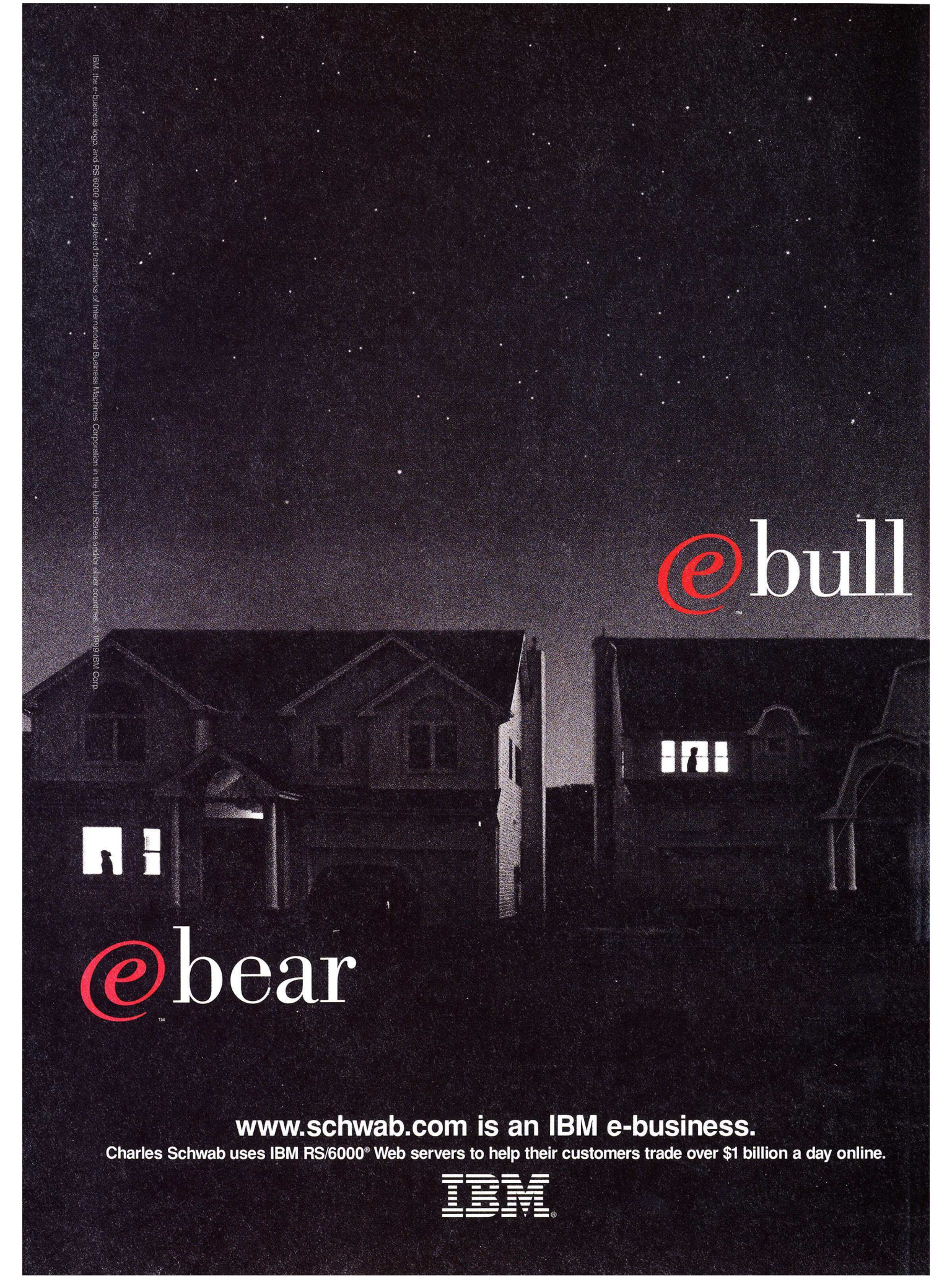

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IBM®

The Law of the Rathole

BUSINESS HISTORY CAN BE HIGHLY MISLEADING. Why? It's written by the winners. Historians spend careers studying the making of the atomic bomb, but not the making of the atomic-powered plane (a spectacular Air Force failure). Research managers analyze DuPont's development of nylon, not Coca-Cola's creation of New Coke (a dud).

We need to pay more attention to the losers, because they can help us understand why innovators fail and when engineers should fold a project. I was reminded of this recently when Boeing, the world's leading aircraft maker, announced the cancellation of a planned supersonic aircraft that promised to carry 300 passengers from Los Angeles to Tokyo in four hours and 20 minutes.

The experimental plane faced technical hurdles and required perhaps another 20 years of incubation. It wasn't likely to meet future noise and emission standards either. But what really worried Boeing's managers were surveys that found that neither passengers nor airlines would pay much of a premium for the plane. Boeing feared it would end up with a pathbreaking plane no one wanted.

Boeing folded at the right time. The company's action revealed an appreciation for one of the great laws of innovation, the Law of the Rathole. It is a simple law: Know when to quit.

The rathole law isn't popular. We live in a time when consultants routinely tell managers they aren't "change-oriented" enough or that they're afraid to make "quantum leaps" in processes and products. What the conventional wisdom misses is that many companies and lone inventors face the reverse problem: They are bold to the point of self-destruction.

Knowing when to walk away from a risky project, then, is as important as knowing when to stay the course. Here are five rules of thumb for deciding when to walk:

■ *Don't Marry a Technology:* Innovators fall in love with technologies at their peril. Often companies squander huge sums of money in order to satisfy the technical intuition of a senior manager. Sometimes older technology is better, if only because social, political and economic factors shape success and reinforce the position of existing techniques. That people the world over dislike the sonic boom effectively doomed the Concorde.

■ *Monitor Your Developers:* At too many companies, research and development is kept in a black box. Managers know the box they need, but not the boxes inside the black box. To avoid a nasty surprise, managers must monitor a project from top to bottom. Bill Gates of Microsoft provides the model here. When he reviews the progress of a project, he meets with every layer of developer, which gives him a chance to sniff out differences of opinion and snags.

■ *Create Rival Ratholes:* Two mistakes can be better than one. Consider the experience of Ashton-Tate, the leading maker of database software at the end of the 1980s. It needed a new version of its flagship program, but its development team scrapped one design after another. By the time the CEO assigned a new team to the task, it was too late. Ashton-Tate was dying, and the board fired the chief. Had he had two teams from the start, he might not have had a new program, but he would have realized the severity of his situation much sooner—and possibly saved the company by heroic measures.

■ *Spread the Risk*: Some of the costliest projects, from new airplane engines to memory chips, are supported by alliances, not single companies. This cuts down the rewards of success—but also the size of the rathole.

■ *Manage Expectations:* Big projects draw lots of attention from employees, investors and the tech-mad public. It is tempting to fuel the frenzy with grand claims. These make news. But leaders manage expectations. Often the hardest part of halting a muddled project is the loss of face that accompanies the decision. This loss is reduced sharply by having talked intelligently about the pursuit of innovation in the first place.

Knowing when to walk away from a risky innovation is as important as knowing when to stay the course.

Follow these five rules, and the chances diminish that a pet project will vanish down the rathole. Look at Boeing. The airline maker certainly wasn't married to supersonic technology. It spread its risks, essentially getting a silent partner, the U.S. government, to pick up a big piece of the tab. It understood customer needs and considered the social and political requirements needed to succeed with a supersonic plane. Finally, Boeing's top managers had a realistic picture of the technical hurdles it faced.

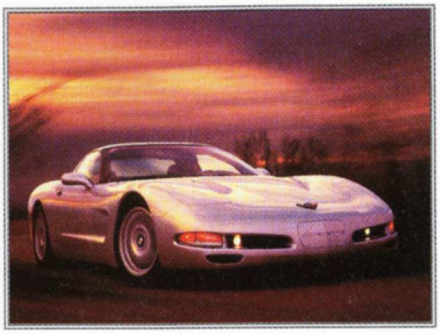
Yet even Boeing fell short in some areas. It failed to manage expectations well, making its decision seem more like a black eye than it should. And it leaves the impression that the next generation of flight technology is a mountain that no one can climb, undercutting the company's competitive image and feeding a potential hysteria over stagnation in commercial aviation. Finally, Boeing picked a time of financial stress—of layoffs and cutbacks in new jet orders—to drop the project. So even though the company obeyed the Law of the Rathole, it gives cynics the room to sneer that it merely responded to a short-term crisis by tossing its future overboard. And that's the wrong message. ◊

{The honest-to-goodness trut

If we had just removed the roof

By David Hill, Co

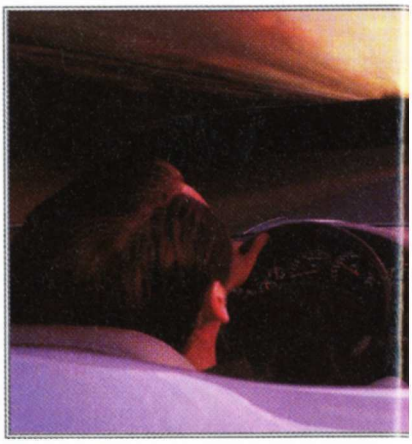
One of the primary objectives when we designed the C5 Corvette® was to make sure it handles superbly. We would not be happy with



{ The coupe has the same stiff structure, rear-mounted transaxle and revised suspension as the convertible. }

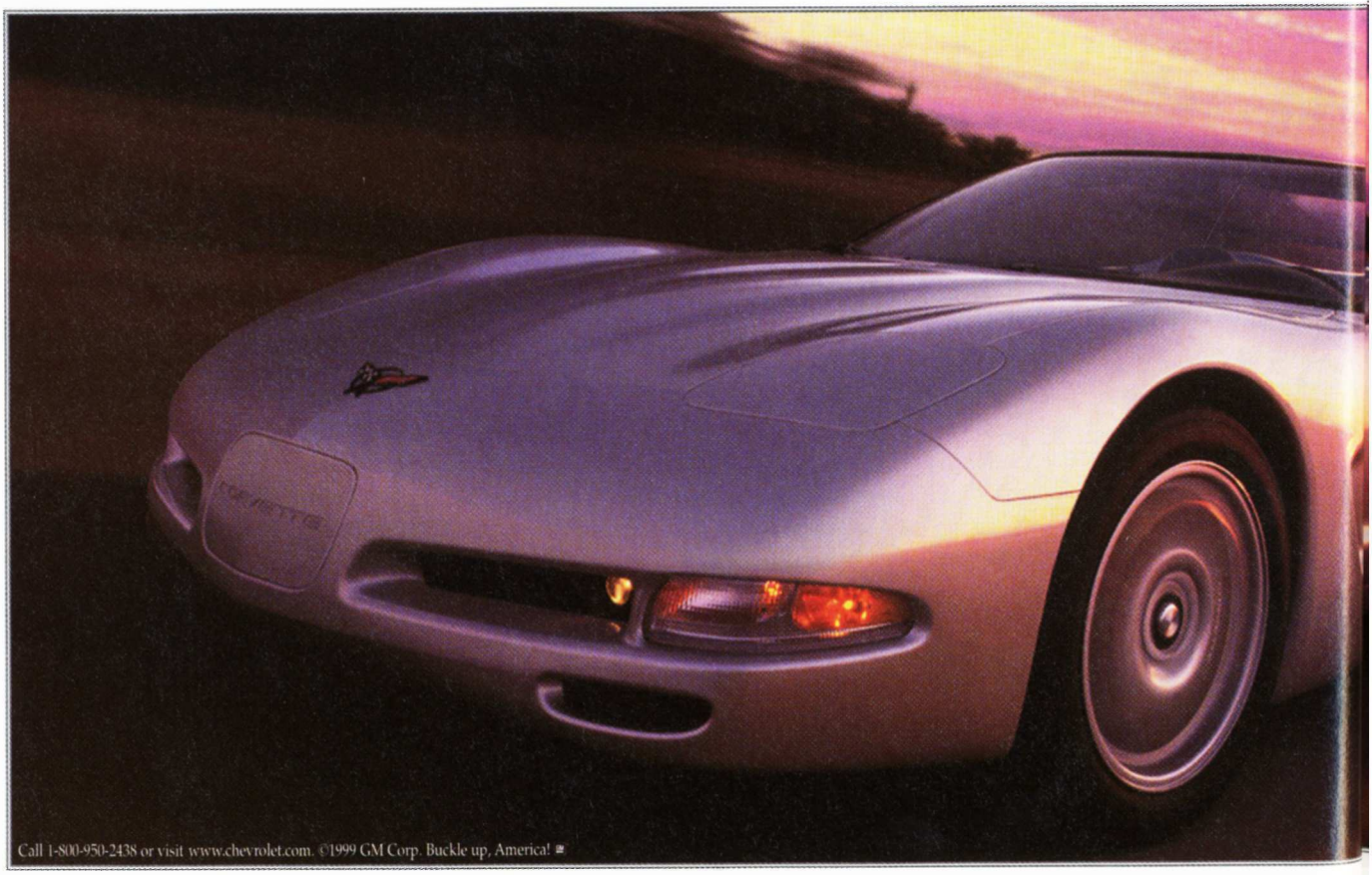
anything short of an outstanding sports car, whether a coupe, convertible or hardtop. It was critical that we didn't just take the coupe and chop off the top to make a convertible. The fact is, the C5 Corvette was designed as a convertible right from the outset. It was the best way, the only way in our minds, to make a car with extraordinary feel and handling.

Stiffness and Strength We didn't want this car to suffer from the ride setbacks other convertibles typically have. One particular concern was how to avoid cowl shake, a common side effect of removing a car's roof. So, we made the structure very rigid. The previous 48-piece frame rails were replaced with twin seamless hydroformed tubes. Our new hydroformed frame rail is much more durable than a welded-up one. In fact, the structure was tested to endure up to three lifetimes of Corvette usage. And not only is the C5



{ The C5 was designed without a roof from the start so

four times stiffer structurally than its predeces it also has a lower curb weight. The difference in rigidity is immediately noticeable; lateral shake is virtually gone, even in the absence of a structural crossover bar.



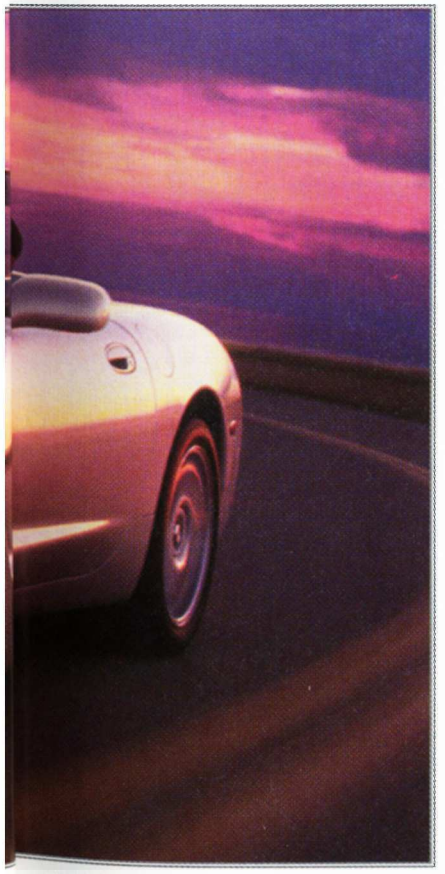
bout the C5 Corvette, after all.}

t would have been a tragedy.

tte Chief Engineer

uld make a world-class sports car that's also a convertible. }

User-Friendly Convertible Once we perfected the tructure, our next priority was to make every illimeter of the car work for the driver, especial- in terms of comfort, spaciousness and cargo. Ve wanted the car to be easy on the driver, a rare feat in convertibles. So, the controls and functions were placed where it would be natural to reach for them. Entry and exit are easier because door-sills are almost four inches lower. We've increased the hip, shoulder and leg room. There is four times more cargo space with the top down than with a C4. Partly responsible for this are the run-flat tires, which make a bulky and weight-adding spare tire unnecessary. (The instrument panel will alert drivers when a tire needs air.) These measures were taken simply because we wanted customers to avoid inconvenience wherever possible.

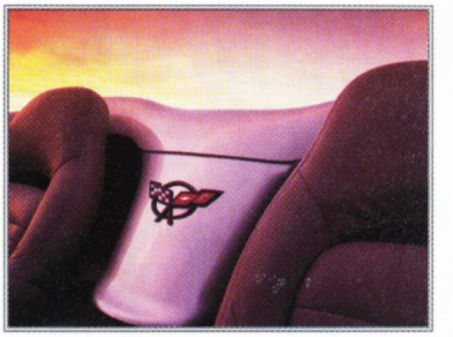


Power and Performance An obvious worry was whether we would lose the true spirit of a sports car by making it too civilized. We went to great lengths to keep that spirit alive. The 1999 Corvette has an aluminum small-block V8 that produces 345 horsepower at 5600 rpm, 350 lb.-ft. of torque at 4400 rpm and, in coupe form, achieves a top speed of around 170 mph.

Although it delivers more horsepower and torque than the iron version it succeeds, the C5 engine weighs 44 pounds less and is smaller in size. Basically, we packed more power into a more compact unit. We could keep the hoodline low, which would improve both aerodynamics and driver visibility.

Making No Compromises Perhaps the most vocal customer opinion was that they wanted a no-compromise sports car; they didn't want to sacrifice ride comfort for the sake of performance. We found breakthrough methods to meet those requirements. Like the composite, balsa wood-cored floor. It minimizes vibrations for the cockpit occupants, while being both lightweight and strong enough to help deliver a more fatigue-free driving experience.

The stiff structure and revised suspension also demonstrate how there are no take-aways in the C5 convertible. By shifting the transaxle to the rear, we opened up more leg room. This also freed up room for a structural tunnel down the middle of the car, which increased its rigidity. That rigidity lets the suspension do its job properly; instead of compensating for chassis flex, it can focus on the most important things: precise handling and a smooth ride.



{ Design attributes like the nostalgic waterfall make the C5 immediately recognizable as a Corvette. }

A True Corvette The C5 convertible proves it is possible to marry high performance with top-down freedom. Simply put, this thing is incredible. It will far exceed people's expectations. It even exceeded mine. See why on the showroom floor.

The Only Sports Car That Matters.

CORVETTE

HUMACHINES

BY STEVE MANN

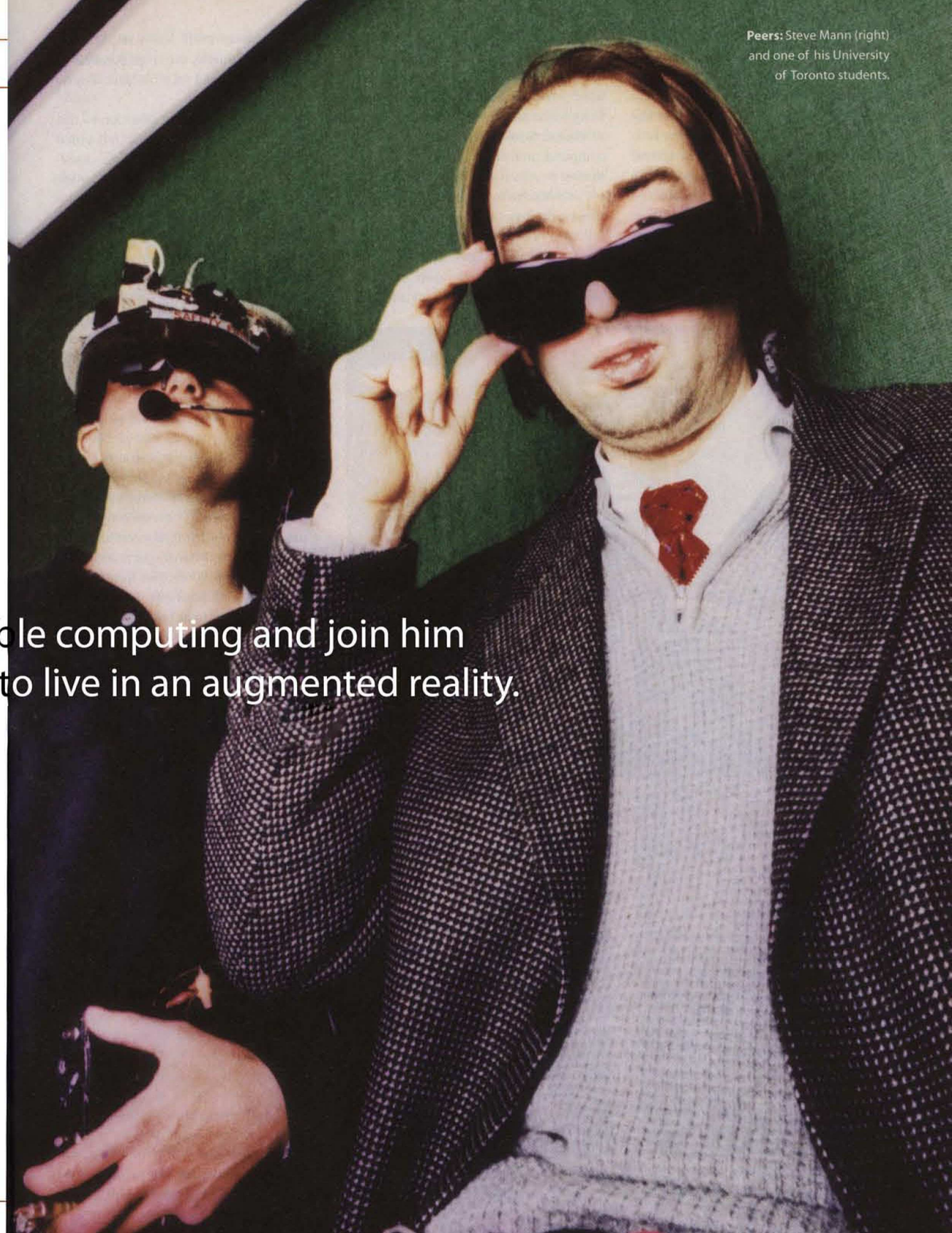
Cyborg Seeks Community

Meet one of the creators of wearable computing and join him in his search for like-minded folks to live in an augmented reality.

Steve Mann began tinkering with wearables as a Canadian teenager. He developed his vision further at MIT's Media Lab in the 1990s. Today, Mann may be the world's only full-time "cyborg." He is clad in his wearable computing system almost everywhere he goes, relying on its sensors and network connections to augment his experience of the world. Technology Review *asked him to tell the story of the creation of the Mann/machine.*

PEOPLE FIND ME PECULIAR. THEY THINK IT'S ODD THAT I SPEND MOST OF MY WAKING HOURS WEARing eight or nine Internet-connected computers sewn into my clothing and that I wear opaque wrap-around glasses day and night, inside and outdoors. They find it odd that to sustain wireless communications during my travels, I will climb to the hotel roof to rig my room with an antenna and Internet connection. They wonder why I sometimes seem detached and lost, but at other times I exhibit vast knowledge of their specialty. A physicist once said he felt that I had the intelligence of a dozen experts in his discipline; a few minutes later, someone else said they thought I was mentally handicapped.

PHOTOGRAPHS BY RICK CHARD



Peers: Steve Mann (right) and one of his University of Toronto students.

Despite the peculiar glances I draw, I wouldn't live any other way. I have melded technology with my person and achieved a higher state of awareness than would otherwise be possible. I see the world as images imprinted onto my retina by rays of light controlled by several computers, which in turn are controlled by cameras concealed inside my glasses.

Every morning I decide how I will see the world that day. Sometimes I give myself eyes in the back of my head. Other days I add a sixth sense, such as the ability to feel objects at a distance. If I'm going to ride my bicycle, I'll want to feel the cars and trucks pressing against my back, even when they are a few hundred feet away.

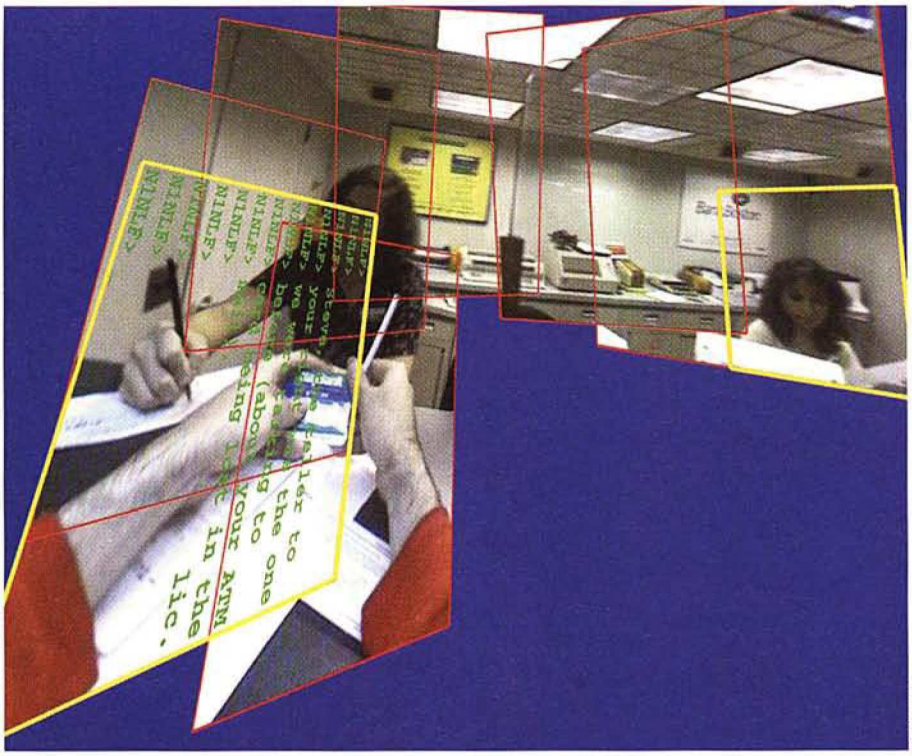
Things appear different to me than they do to other people. I see some items as hyperobjects that I can click on and bring to life. I can choose stroboscopic vision to freeze the motion of rotating automobile tires and see how many bolts are on the wheels of a car going over 60 miles per hour, as if it were motionless. I can block out the view of particular objects—sparing me the distraction, for example, of the vast sea of advertising around me.

I live in a videographic world, as if my entire life were a television show. And many people assume that by living my life through the screen, I do exactly what television leads us to do—tune out reality. In fact, WearComp has quite the opposite effect: Visual filters help me concentrate on what is important, heightening my sensitivity and setting my imagination free. I do of course have occasion to remove my computational prostheses, as when I sleep, shower or splash around in the ocean.

In addition to having the Internet and massive databases and video at my beck and call most of the time, I am also connected to others. While I am grocery shopping, my wife—who may be at home or in her office—sees exactly what I see and helps me pick out vegetables. She can imprint images onto my retina while she is seeing what I see. I hope to add to the population of similarly equipped people; last fall at the University of Toronto, I taught what I believe to be the world's first course for cyborgs *(see "School for Cyborgs," p. 40.)*

Much of my passion has been fueled by a desire to restore some balance of privacy in a world where individuals are increasingly affronted by government surveillance and corporate encroachments. In fact, one goal of my work was to challenge the notion of totalitarian video surveillance—the now-common practice of a corporate or governmental establishment wishing to know everything about everyone in the establishment while revealing nothing about itself. Many department stores, for example, use large numbers of hidden cameras and yet prohibit customers from taking pictures.

I attempted to draw attention to this phenomenon of unreciprocated video surveillance in *Shooting Back*, a documentary I made during my day-to-day life in several different countries over a period of many years. Whenever I found myself in a store or some other establishment with electronic eyes perusing the premises, I asked its management why they were taking pictures of me without my permission. They would typically ask me why I was so paranoid and tell me that only criminals are afraid of cameras. Of course I was covertly recording this response using my own hidden eyetap video camera. Then I would pull an ordinary camcorder out of my satchel and give them a chance to explain their position for the record. (The camcorder was simply a prop, of course, as the eyetap camera had been capturing the scene.) The same people who claimed that only criminals were afraid of cameras had an instantly paranoid (and sometimes violent) reaction to my camcorder. *Shooting Back* was, I believe, the first documentary to be transmitted in real time to the World Wide Web while it was shot. (Selected portions of *Shooting Back* may be viewed at http://wearcam.org/shootingback.html.)



STEVE MANN

Shared vision: In this scene from Mann's documentary *Shooting Back,* the yellow-bordered panels indicate where he and a remote collaborator are directing their attention at the moment.

Ahead of My Time

Growing up during the 1960s and early 1970s, I always seemed to be creating things before their time. I grew up in Hamilton, Ontario—a city on the western tip of Lake Ontario about 100 kilometers from Toronto. I came by this inclination naturally; during the early 1950s, my father had built what was perhaps the first wearable radio. (He had pursued radio as a hobby since his childhood.) He had taught me quite a bit about electronic circuits by the time I started kindergarten. As a young child, I removed the head from a portable battery-powered dictating machine and replaced it with the head from a high-fidelity audio cassette deck. From this cassette transport mechanism, I built a system that enabled me to listen to music while walking around. While many people scoffed at this invention, I found it nice to be able to drown out background music while shopping, to

assert my own idea of personal space, and to defend myself from theft of my solitude by the department stores with their Muzak.

In my teens I founded a concept of mediated reality, which I called "lightspace." The goal of lightspace was to experience an altered perception of visual reality by exploring a large range of possible forms of illumination while observing a scene or object from different viewpoints. My work with lightspace led to the invention of my wearable computer. My desire to create photographic instruments that would function as true extensions of my mind and body—and my desire to control these photographic instruments in new ways—created a need for the ability to program complex sequences of events.

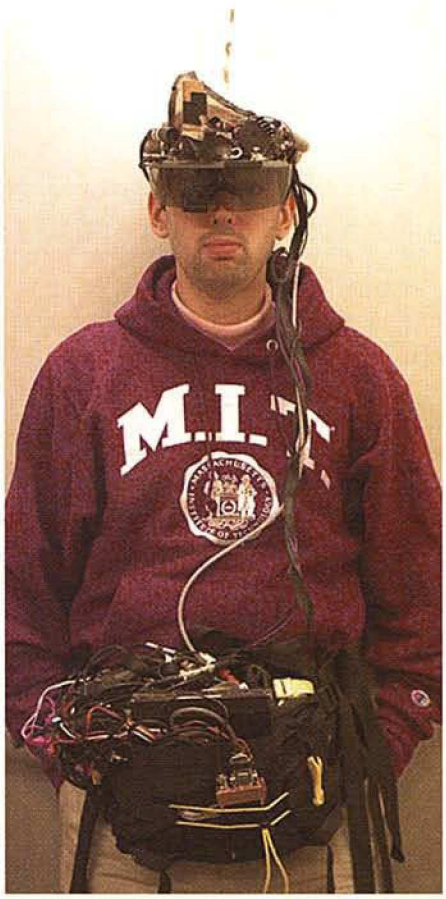
I began to take this matter seriously, building a digital computer from a large number of electronic components salvaged from an old telephone switching computer. I did much of this experimentation in the basement of a television repair shop where I spent much of my childhood as a volunteer, fixing TV sets. In this shop I built up a great deal of knowledge about electronic circuits.

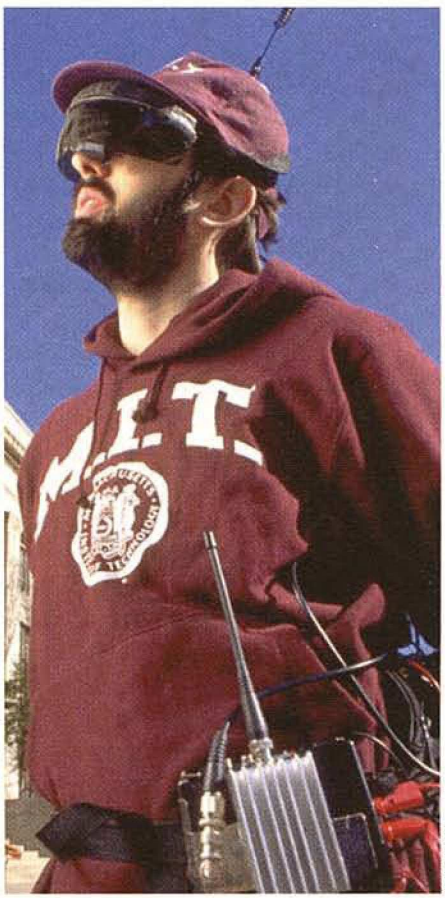
The result of my early efforts was, in the early 1970s, a family of wearable computers I called "WearComp0." Sometimes I took these cumbersome prototypes outside in search of spaces dark enough to explore the altered perception of visual reality I could create using portable battery-powered light sources. People would cross the street to avoid me, not knowing what to make of what must have looked to them like an alien creature. The rig was physically a burden, weighing as much or more than I did. After wearing one of these encumbrances from sundown (when it got dark enough to use them) to sunrise, my feet would be swollen, blistered and bleeding.

I continued to refine WearComp0 and its evolutionary successor, WearComp1. After much tinkering, I came up with WearComp2—my first system that truly qualified as a wearable computer in the sense that it was not just a special purpose device. WearComp2 was field programmable, with a full-function input device (a keyboard and joystick for cursor control both built into the handle of an electronic flashgun), text and graphical displays, sound recording and playback (crude, home-brew analog-to-digital and digital-to-analog converters), and a wireless data connection to provide links to other computers. I completed this system in 1981, before most of the world realized that computers could be portable, much less wearable.

Though an advance over my earlier prototype, WearComp2 was still a burden to lug. I wanted to reduce its bulk and

"Every morning I decide how I will see the world that day. Sometimes I give myself eyes in the back of my head, or a sixth sense."





STEVE MANN

Evolution of a cyborg: Mann's wearable rig has gone from the helmet of 1980 (left) to the visor of 1990 (center) to the more compact unit of 1995 (right). He has continued to make the system less conspicuous; people no longer cross the street to avoid him.

make it look more normal. This goal led me in 1982 to experiment with building components directly into clothing. I learned how to make flexible circuits that could be embedded into ordinary fabric. This work enabled me to make versions of WearComp that were not only more comfortable to walk around in but also less off-putting to others.

In spite of these advances, my life as a cyborg remained mostly solitary. I did connect quite literally (by serial data cable) with an understanding woman during my freshman year at McMaster University in my hometown of Hamilton. We faced unusual challenges in this configuration, such as having to choose which public restroom to use when we were joined. Thinking back, I imagine we must have made a comical sight, trying to negotiate doorways without snagging the cable that tethered us together.

Such relationships were rare, and it was seldom that I could get others to wear my seemingly strange contraptions. Many people were unable to get past my technological shell, which they apparently found more than a little odd. Still, multimediated reality had provided me with a unique vision of the world, and by the mid-1980s I had a following of people on the fringes of society who shared (or at least appreciated) my vision. I was invited to shoot pictures for album covers and hair ads. By 1985, I began to realize that it wasn't just the finished photographs people wanted; they also seemed to enjoy watching me take the pictures. Often I would be shooting in large warehouses, with audiences of hundreds of people. I began to realize that I had become a cyborg performance artist. By the end of the 1980s, however, I found myself yearning to return to my more substantive childhood passions for science, mathematics and electrical engineering.

While at McMaster, I added biosensors to the WearComp so that it could monitor my heart rate (as well as the full EKG waveform) and other physiological signals. I also invented the "vibravest"—a garment studded with radar transceivers and vibrating elements. Wearing this vest made objects at a distance feel as if they were pressing against my body. I could close my eyes and walk down the hallway, confident that any wall or other obstacle would be felt as warning vibrations on the appropriate side of the vest. By sparing

School for Cyborgs

Engineering students cross the human/machine gap—or do they? BY STEVE DITLEA

The black sunglasses perched on Steve Mann's forehead provide a rare tinge of high-tech glamour in a drab classroom in the University of Toronto's Department of Electrical & Computer Engineering. Wearing a ribbed red-and-gray sweater, Mann appears, to a casual observer, quite normal. And the class he teaches—"ECE 1766: Personal Imaging and Photoquantigraphic Image Processing"—seems ordinary. You'd never know the 20 students were recruited via a campus flyer bearing the headline: YOU WILL BE ASSIMILATED. BECOME THE WORLD'S FIRST "CYBORGS."

For anyone weaned on TV's latter-day *Star Trek* series and their vision of half-computer/half-humans losing their individuality to the collective consciousness known as the Borg, the notion of being absorbed into a computer-mediated entity terrifies and fascinates. As the pioneering class on becoming a cyborg, this one-semester offering for graduate students and fourth-year undergrads has attracted a smattering of casually dressed men and one woman. The polyglot group includes students from Germany and Iran, as well as Canadians with family ties to Asia and the Middle East. It is, in fact, the embodiment of *Star Trek*'s multiethnic ethos.

Wearable PCs, brick-sized, with awkward monocular head-mounted displays, rest on the desks of just two students—the only overt sign that this may be a milestone of human-computer interaction. The wearable computers—commercially available systems on loan from manufacturer Xybernaut—are curiosities on a campus more familiar with notebook and palm computers. As students concentrate on their teacher's words, no wearables are actually in use.

Or so it seems. But look more closely at Mann and you see more than a dozen bulges straining the fabric of his striped sweater, like some *Alien*-movie spawn

Final exam: Mann's students at the University of Toronto don commercial wearable systems from Xybernaut. His aim: "Humans and computers, inextricably intertwined."

about to burst from his body. He trails a gray cable, an old-fashioned plastic rocker switch, some black, red and gray wires, and a miniature keyboard—items that just miss getting caught on the edge of his desk as he paces on and off the dais. Under his sweater Mann wears a lightweight wearable computer of his own design, wirelessly linked to the Internet and to his documents, which he can access in a screen hidden behind his glasses. In his computer-ready state, Mann is the only cyborg in the room—the master imparting esoteric knowledge to a new generation, knowledge that will allow them to become cyborgs, too.

For a few hours the previous week everyone in the class wore Xybernaut computers as they participated in what Mann calls their "first project as a community of cyborgs." Linked by a few cell phones, this pod of borgs toured the campus, capturing images using Mann's "lightspace" photographic technique.

Next week, for the course's "open eye" final exam, students are to wear Xybernauts "as an aid for calculations, as a memory prosthesis, etc.," according to the paper he hands out. Mann adds: "This may well be the world's first exam involving the testing of a class of cyborg entities—humans and computers, inextricably intertwined."

Grand thoughts, but here in the classroom, the cyborg vision has run into hard-edged reality. The Xybernaut systems, designed originally for defense and industrial applications, aren't really all that wearable—at least, not comfortably for more than minutes at a time. "It's bulky, it's heavy," says fourth-year undergrad Greg Harmandayan. Classmate Daniel Friedmann concurs: "What you wear on your waist and this head-mounted display isn't what I thought of as being completely wearable." Special student Stephen Ross, on a break from his full-time job, complains that "the equipment's battery life is too short to allow us to go online for any extended amount of time."

Not only does the hardware fall short—there are some human deficits as well. In winnowing down 40 applicants for the class, Mann insisted on knowledge of computing fundamentals. He later explains: "I said right up front that to succeed at this class, people better not be afraid of mathematics or of operating systems, getting down and dirty with the kernel." Unfortunately, the students who take the class are accustomed to Windows-based computer systems, and have required several weeks to acclimate themselves to the do-it-yourself tweaking of Linux, Mann's operating system of choice for his and his students' wearables. (A Xybernaut PC runs uncomfortably hot with Windows, remaining considerably cooler with Linux's more efficient code.) But the delay in Linux literacy slows Mann down, leaving him unable to cover as ambitious a syllabus as he would like during limited class hours.

When Mann teaches the course this summer in an immersion-intensive form, he plans to avoid both problems. "I might say as a prerequisite that you've already got to be a cyborg with your own equipment. I would take 20 or 30 people from around the world who are already cyborgs." And when ECE 1766 starts again in the fall, Mann expects students to be issued Xybernaut's next generation of wearables—faster, more compact systems manufactured through an arrangement with Sony.

For Mann, though, the computing hardware is incidental to a wider vision of "humanistic intelligence"—of computer-complemented humans in a multimedia world. "Wearable computing is meaningless in and of itself," he says. As he sees it, the personal computing applications of wearables stressed by commercial manufacturers such as Xybernaut are a mere subset of the visual recording, interpretation and augmentation functions of his own systems.

Having spent much of his life achieving oneness with his machine, Mann sometimes seems to forget how remarkable his accomplishment is. "How to be a cyborg is a totally boring concept," he insists. "The fundamental mathematical basis behind it makes it interesting. Otherwise, it's not much of a course."

Despite the doubts about their comfort and practicality, 16 of the 20 Xybernaut computers signed out by ECE 1766 students remain at large following completion of the course. Several students are exploring the possibility of graduate study with Mann. Almost all have been marked for life. They have been assimilated.

myself from the cognitive load of processing all that visual information, I found I was able to think more clearly.

In 1991, I brought my inventions to MIT as a PhD student. As a cyborg, uprooting myself from Canada was a formidable task, since I had installed my cyberbody in Canada over a period of many years. Going to MIT was a sudden move of my extended self.

First, I secretly climbed up onto the rooftops of buildings around the city to put in place the wireless data communications infrastructure I had brought with me from Canada. I had to quickly deploy my base stations at the top of elevator shafts or anywhere else I could find warm dry places. This way, whenever I wanted an Internet connection, these gateways would be ready to send the data to me, no matter where I was—even if I was in a basement or riding on the subway.

Although I kept in touch with my family through cyberspace, my first two years at MIT were lonely times IRL—in real life. I was, after all, the only person there with a wearable computer. Then in 1993, at the request of a fellow student, a local engineer named Doug Platt built a wearable system. I was no longer the only cyborg at MIT.

It took some years to get other cyborgs at MIT, thus enabling the beginnings of a sense of community. Although I never succeeded in getting a large community outfitted with my high-speed packet radio systems, the cellular telephones that began to emerge provided another answer to the problem of connectivity.

STEVE MANN

Unmasked: The Mann behind the machine, shown here in 1985 during his stint as a computer-assisted photographer in Canada.

idea and in 1996 the Computer Society responded with an overwhelming "yes." This marked a turning point in my acceptance by my professional peers.

More than 700 people attended this first IEEE-sponsored symposium on wearable computing, held in Cambridge, Mass., in October 1997. A gala "Wearables" event the following day drew 3,000 people. In that same year I received my doctorate from MIT in wearable computing. This was a gratifying culmination: I had turned a childhood hobby and passion into an MIT project, the topic of a conference, and a PhD dissertation.

This past year I returned to Canada to pursue my work at the University of Toronto. Why Toronto? I had lived there in the mid-1980s, and the city had seemed very "cyborg-friendly." I had sensed there a cosmopolitan diversity as well as a genuine warmth and openness that contrasted with the more cyborg-hostile and tense atmosphere of some large U.S. cities.

Wearing Well

ALTHOUGH I SPENT MANY YEARS developing WearComp in relative isolation, I welcome efforts to commercialize wearable computers. At the vanguard is Xybernaut, based in Fairfax, Va. Xybernaut's latest model is being manufactured by Sony, indicating that the Japanese electronics giant has an interest in what some believe will become the Walkman of computing. Last May, Xybernaut organized its own conference on wearable computing (and invited me to give the keynote address). I may also begin to license some embodiments of my original WearComp, as well as many of my more recent innovations, to companies who want to manufacture commercial systems. I think it will be especially important to make the cyborg outfit less cumbersome—something that's long been a goal of mine. My latest version is quite sleek, and looks just like ordinary bifocal eyeglasses, with the eyetap point hidden along the cut line. Even when fully rigged, I can still play an acceptable game of squash.

I realize that some people see me and my invention as a potential threat—like the Borg of *Star Trek* fame: "You will be assimilated." Clearly, there are important philosophical issues to be explored. Not only is there the danger of the technology being used to monitor people to make them into obedient productive cyborgs, but there is also the potential that people will become too dependent on this technology. My goal as a responsible inventor and engineer, however, has always been to encourage the development and manufacture of wearable computers as a means of personal, not institutional, empowerment. That will make worthwhile all the obstacles and challenges I have faced during my more than 20 years of developing this technology.

I hope that if I bring WearComp to market, anyone who wishes to will eventually be able to become a cyborg. We'll live in a collaborative computer-mediated reality that will allow us to no longer need to distinguish between cyberspace and the real world. And then this cyborg will have lots of company. TR

"It will be important to make the cyborg outfit less cumbersome. Wearing my latest version, I can still play an acceptable game of squash."

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HUMAN ACHIEVEMENT

The Merrill Lynch forum

BY VICTOR D. CHASE

Seeing is Believing

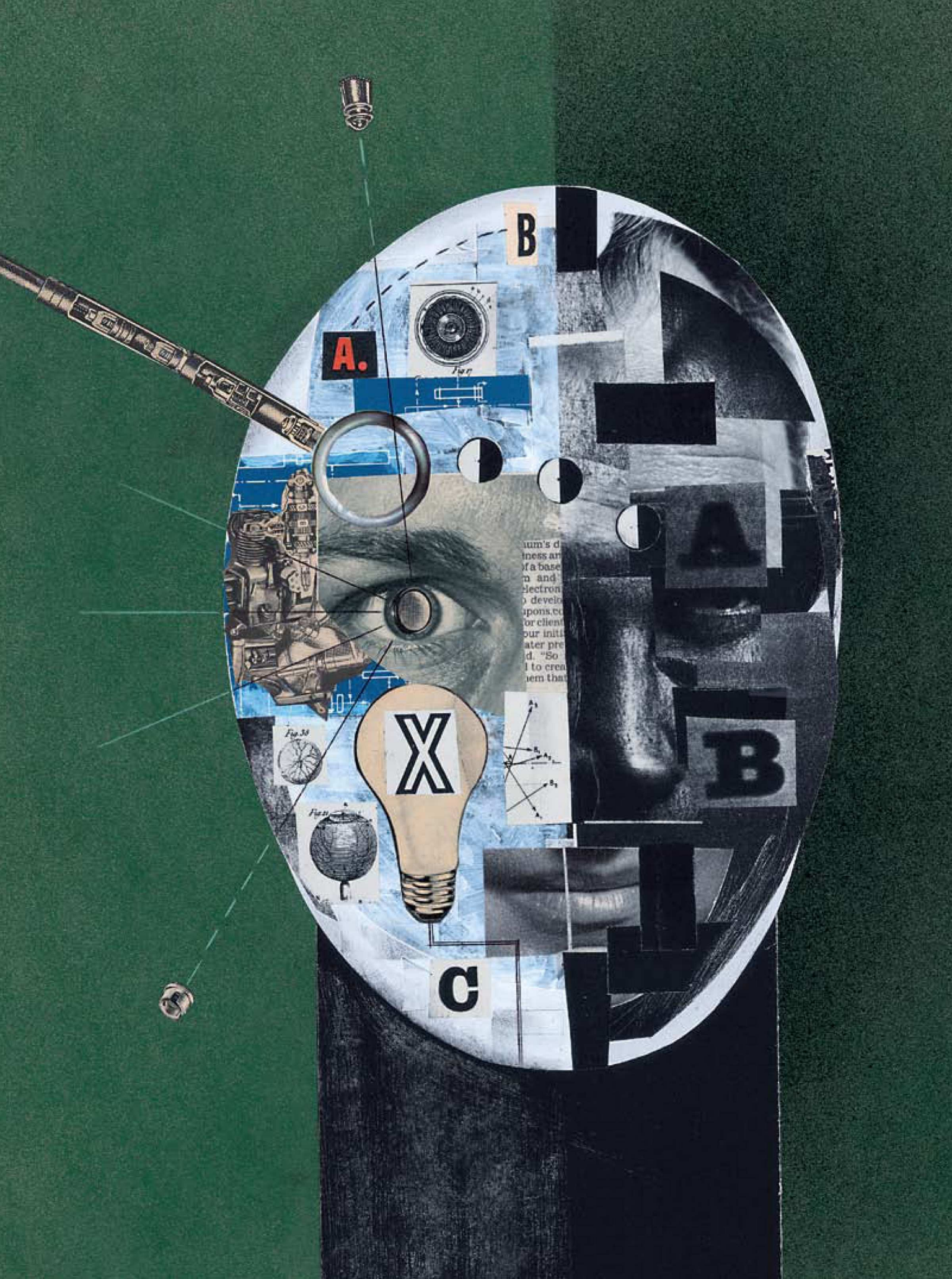
There's a ways to go yet, but the artificial retina is poised to move out of academic labs and into corporate R&D.

COULD SEE IT. JUST A LITTLE LIGHT. THAT'S ALL IT WAS," RECALLS 71-YEAR-OLD Harold Churchey. Not a very dramatic statement—until you realize that Churchey is completely blind.

The sudden spark of vision in Churchey's brain was caused by a jolt of electricity coming from the tip of an electrode introduced into his eye minutes earlier by ophthalmologists Eugene de Juan and Mark Humayun. Churchey could not see the men's faces. But if he had, he might have witnessed their masks of professional anxiety give way to twin grins of "Eureka!" After all, the 1992 experiment at Duke University was a landmark in the fast-accelerating quest to give artificial sight to the blind.

De Juan and Humayun, now professors at the Johns Hopkins University's Wilmer Eye Institute, are among several teams of physicians, engineers

ILLUSTRATIONS BY DAVID PLUNKERT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Masters of light: Experiments by ophthalmologists Mark Humayun (left) and Eugene de Juan (right) help to show artificial vision could be possible.

PHOTOGRAPH BY CHRIS HARTLOVE

and scientists moving to adapt advances in microelectronic technology to create implantable synthetic vision systems. The incredible prospect of bionic vision, says Terry Hambrecht, director of the National Institutes of Health's Neural Prosthesis Program, was less-than-credible "even a few years ago. The technology wasn't there, and neither was the neuroscience. But now a lot of basic research and device development are coming together to make it possible."

Hambrecht's Neural Prosthesis Program doles out $7 million a year in support to a host of seemingly fantastic projects *(see "Direct to the Brain," p. 48)* that take advantage of the fact that the human body is a largely electric machine—one whose damaged motor and sensual circuitry researchers now think they may be able to repair with electronic hardware. In some cases, they already can: The first prosthesis to successfully restore a human sense, the cochlear implant, became a weapon in physicians' arsenal against deafness during the 1970s. Since then, the implants have restored hearing to some 25,000 profoundly deaf people *(see "The Implant Heard 'Round the World," p. 49).*

The eye may be next. In both the United States and Europe research groups intend to build silicon-based implants that can fill in for injured cells in the retina, the light-sensitive tissue that lines the inside of the eye. At least two startup companies—one in Illinois and one in Germany—have already formed to commercialize artificial retina designs, and other academic teams are on the lookout for corporate allies that can help transform their silicon dreams into reality.

These projects aim to use microelectronics to replace the function of the retina's photoreceptors, cells known as rods and cones. These cells are the "eyes' eyes"—the cells that detect light—and are also the

target of two of the primary causes of vision loss. One is retinitis pigmentosa (RP), the inherited, degenerative disease that ravaged Harold Churchey's sight and that of some 40,000 other people in the U.S. and more than a million worldwide. The other major disease affecting the retina is macular degeneration, which blinds about 100,000 people each year, making it the major cause of blindness in people older than 55 in the western world. Together, these two diseases cause about 25 percent of blindness.

No drug or surgery can help the victims of degenerative retinal diseases—or even slow the onset of blindness.

RIGHT NOW, THERE'S NO DRUG OR surgery that can help these patients, or even slow the onset of blindness. The retina is such an extremely delicate outcropping of the brain, according to Humayun, that once it is damaged, "unlike some other structures in the body, there's not much you can do. You're at the end of your know-how." Ophthalmologists can do little more than record the steady loss of sight. For young patients (RP can strike children as young as two or three) they must counsel parents on careers for the blind.

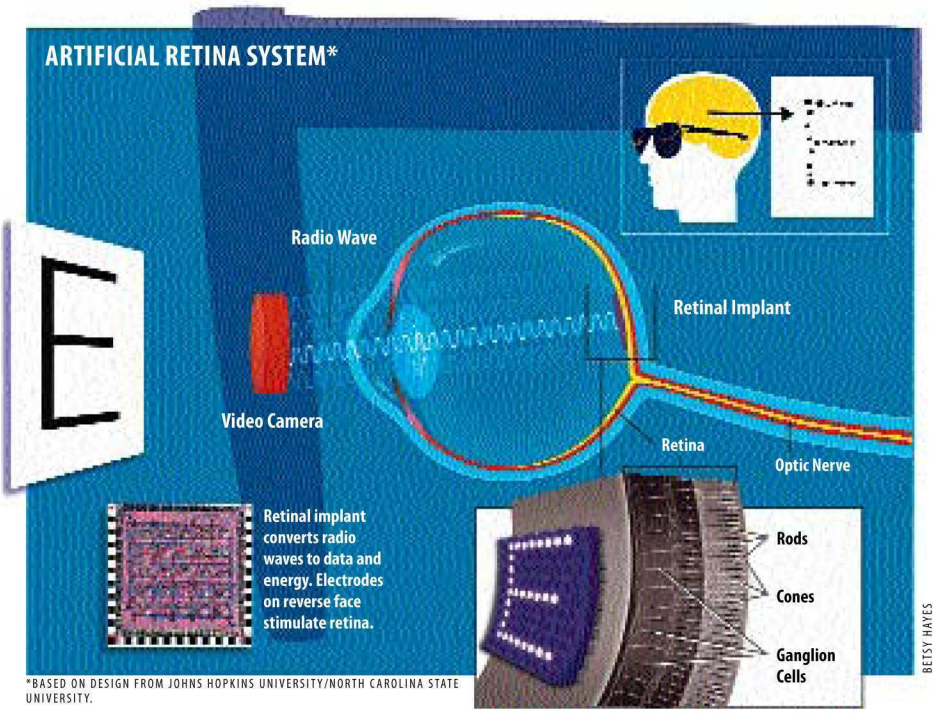
It's a sad business to face "day in and day out," Humayun says, and part of what prompted him and colleague de Juan to start thinking about artificial retinas when they met at Duke in the late 1980s. The pair posited that despite the loss of photoreceptor cells, other nerves in the retina probably remained intact. If that were true, a prosthetic device that could turn light into electricity might be able to jump-start a blind person's vision.

Although it is tissue-paper thin, the natural retina contains a complex layering of neurons that work together to convert light into electrical nerve signals. Streaming through the pupil, incoming light hits the retina and passes through its outermost layer of transparent ganglions before running into a thicket of more than 100 million rods and cones. These photoreceptors soak up the light, which changes the rate at which they release neurotransmitter packets. The chemicals, in turn, set off a cascade of signaling first in the bipolar cells (which help distinguish between light and dark) and then in the amacrine and ganglion cells. By the time it hits the ganglion layer, the analog light signal has been completely digitized—it is now a series of nerve impulses which the ganglion cells proceed to pump into the optic nerve. The optic nerve's 1 million fibers carry the signal to the brain's visual cortex, the place where we experience vision.

Humayun and de Juan weren't worried about what was happening in the brain. What they needed to know was whether people blinded by a disease like RP retained enough intact retinal circuitry to permit them to get a signal into the optic nerve. To answer the question, they approached the eye bank of the Foundation Fighting Blindness, where they obtained eyes that had been preserved from deceased RP patients so that their cell structure would not deteriorate. Counting the retinal cells at 100-micron intervals, says Humayun, "We found a near-total absence of photoreceptors." That was as expected. The important discovery was that 30 percent to 80 percent of the other retinal neurons were still intact.

A step in the right direction, but it remained to be seen whether the cells remaining in a blind person's retina could function. "We had no idea what the effect of 50 or 60 years of degeneration would be on the response of these cells," says Humayun. There were other unknowns. From animal experiments the team knew how strong an electrical stimulus was needed to elicit a response from the retinal cells, but they had no idea if this signal would produce anything like normal sight. Was it possible that when the current hit the vitreous gel inside the eye, which is 99 percent water, it would simply diffuse out and appear as one huge flash of light? Even if they produced an image, says Humayun, "Would it look like a dot, be blue or green? Would it be something that is appealing, or would the stimulus be so noxious that patients would rather be blind?"

Because these questions could be answered only by a live patient, seven years ago Humayun and de Juan put out the word that they were looking for a volunteer. A colleague put them in touch with Harold Churchey, a former welder who ran a snack bar in Maryland's Washington County Courthouse after RP blinded him. Churchey was game, even though he would have to



*BASED ON DESIGN FROM JOHNS HOPKINS UNIVERSITY/NORTH CAROLINA STATE UNIVERSITY.

remain conscious as the physicians sunk a probe through the wall of his eye, then electrified it. "I might be over the hill, [but] if I can help some young person, I am for it," says Churchey. Later, his twin brother, Carroll, also blind, would join the experiments.

The first of the team's 15 human experiments took place at Duke on September 17, 1992. Peering through Churchey's pupil with a surgical microscope, Humayun pushed a hand-held probe through the white of his eye and back toward the retina. The probe held a single platinum wire, coated with Teflon and embedded in silicone rubber. De Juan and Humayun started applying small electrical pulses of a few hundred milliamps, but for 20 minutes Churchey saw nothing. "You can imagine the level of anxiety as we checked every possible circuit," said Humayun. When the physicians finally pushed the probe so it nearly touched his retina, Churchey announced that he was seeing...something.

"We were able to create a small dot of light exactly under the stimulating electrode," says Humayun. Churchey told his interrogators the spot looked to be the size of a pea seen at arm's length. Worried that it might be some kind of artifact (possibly of Churchey's imagination) the doctors changed the frequency of the pulse, asking him to count out loud if he saw the light. He did, and also reported that the spot moved when the electrode did, proving there was some degree of spatial resolution.

Buoyed by the results of their first human test, de Juan and Humayun set out to determine whether a blind patient could be induced to see multiple spots of light, something that would be crucial if they were ultimately to create a useful image. In their second human test, another volunteer was able to see three spots of light produced by three probes with an edge-to-edge separation of about 300 microns, or the width of a few human hairs.

The next challenge was to answer what Humayun calls "the million-dollar question." Namely, how many electrodes would they need to produce usable images?

When cochlear implants—the predecessor to visual implants, which have given hearing to many deaf people—were being developed, some experts believed that at least 1,000 electrodes would be needed to create coherent sound. Yet six electrodes proved enough to help many patients. "This points to the fact that there is incredible plasticity in the ability of the human brain to take a somewhat crude sensory input generated by a man-made machine and make good use out of it," says Humayun.

Evidence of the brain's forgiving nature had already come out. The volunteers had reported that the electrodes were producing flickering dots of light. To create a steady image, the doctors simply turned up the frequency of the pulse; just as a movie appears continuous, even though it is made up of a series of still pictures, the brain was compensating by keeping an image in mind until the next pulse came along.

In a 1996 experiment, Churchey's third, the two physicians, who had by then moved to Johns Hopkins, placed a 25-electrode array (a 5-by-5 square, with a slightly convex surface allowing it to match the contour of the retina) in Churchey's eye and attempted to create an image of the letter "U" by stimulating the electrodes in a dot-matrix-like format. They had picked the wrong letter. They couldn't round the edges of the "U," and Churchey reported seeing an "H." Since then, de Juan and Humayun have conducted one more experiment, stimulating the outermost electrodes of a square array—the patient reported seeing a matchbox shape.

Although they've been able to create only the crudest kind of image, Humayun says the initial successes have "really lit a

Direct to the Brain

Work is well under way on microelectronic retinal implants that can fill in for damaged nerve cells in the eye *(see main story)* and which may one day restore sight to some blind people. But definitely not to all. Those who have lost their vision in accidents that destroy the retina, or from glaucoma (which destroys the optic nerve), simply don't have enough neural circuitry left in their eyes for a retinal implant to function. But what if you could bypass the eye entirely, and connect directly to the visual cortex, the brain area where images are processed?

That's the thinking underlying an artificial vision system that researchers at the National Institutes of Health's Neural Prosthesis Program (NPP) have been working on since 1969. NPP director Terry Hambrecht says the overall idea is to take images from a video camera and, after some processing, pipe them directly into the gray matter via a cortical implant. Grand concept. The devil, of course, is in the details—hence the 30-year developmental timeline.

Hambrecht says the NIH team spent 15 years developing safe, miniature electrodes able to establish electrical contact with brain neurons. Basic challenges included the brain's movement relative to the skull, which means the electrodes have to move with it, in spite of being hardwired to the exterior. The scientists eventually came up with a 2-millimeter-long, 256-electrode assembly made of gold leads (soft and flexible, to move with the brain) and iridium electrodes (hard and biocompatible, to penetrate the tissue). Although the results are preliminary, Hambrecht says his team has used a lab version of the cortical implant to induce images of light spots in tests on blind people.

The strategy of skipping the sense organ and going directly to the brain can also address causes of deafness that lie beyond the help of cochlear implants *(see "The Implant Heard 'Round the World." p. 49)*. For instance, to treat a tumor called NF2, surgeons have to completely remove the auditory nerve, which connects the inner ear with the brain stem. At the House Ear Institute in Los Angeles, physicians look to help NF2 survivors hear by placing eight electrodes directly on the surface of the cochlear nucleus: the brain's gathering point for auditory data. Only about 100 patients have received the "auditory brain stem implant" so far, and results are still poor compared with cochlear implants.

The problem, says House neuroanatomist Jean Moore, is that man-made components are still too crude to communicate effectively with the brain's complex nerve structure. Trying to convey the world's pitch, tones and timbres with only eight electrical contacts, she says, "is like playing a piano with a sledgehammer." But the House team hopes to do better. With funding from the NPP, they are now designing needle-like microelectrodes that will actually penetrate the cochlear nucleus. If this high-fidelity connection works, it could be music to the brain.

The Implant Heard 'Round the World

"An amazing piece of science" enables the deaf to hear. BY VICTOR D. CHASE

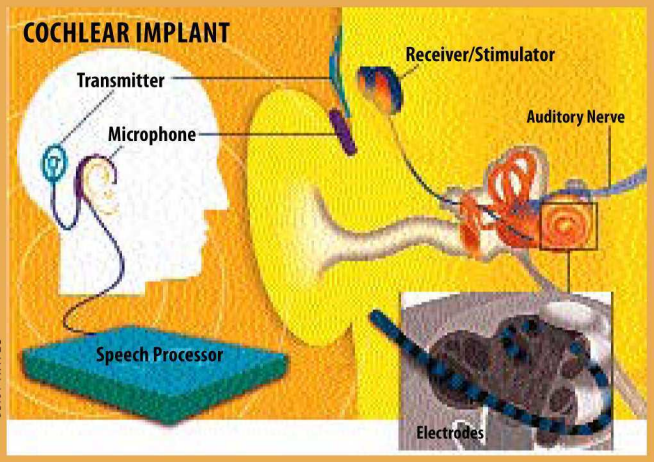
When Michael Pierschalla was 20 years old, he was struck by a rare autoimmune disease known as Cogan's syndrome. In less than a week, the University of Wisconsin student lost his sense of balance and most of his hearing. A second frightening episode, six years later, left him totally deaf.

That Pierschalla was able to discuss these experiences during a recent telephone conversation is a testament to the success of cochlear implants, a type of sensory prosthesis that has restored some level of hearing to more than 25,000 profoundly deaf people worldwide.

Pierschalla's hearing loss—like that of most deaf people—was caused by damage to several thousand delicate "hair cells" that line the base of the cochlea, a snail-shaped, fluid-filled structure in the inner ear. In healthy people, these hair cells act like tiny antennae, picking up sound vibrations and converting them into electrical impulses for transmission up the auditory nerve to the brain.

Starting 30 years ago, scientists found that by slipping electrodes into the cochlea, they could bypass the damaged hair cells and create auditory sensations by stimulating remaining nerves directly. Early implants used only one electrode, and offered limited audio input. But in 1985 Pierschalla was among the first to receive a multichannel implant, a device with six electrodes that provided a breakthrough in sound quality. The number of electrodes has now jumped to 22, accompanied by a dramatic increase in popularity among the deaf.

"It's an amazing piece of science that's come very far," says Pierschalla, who now works for Innsbruck, Austria-based Med-El, one of the three major manufacturers of cochlear implants. Along with market leader Cochlear Corp. of Englewood, Colo., and Advanced Bionics of Sylmar, Calif., the U.S. market for the device is about 2,000 units per year. Currently, the cost of a commercial cochlear implant, surgery and postoperative training is around $40,000. With today's systems, patients wear a microphone tucked behind one ear, hearing-aid style, which captures sounds. The signal first travels through a Walkman-sized external processor (Pierschalla wears his in a shoulder holster) that picks out important speech sounds from noise. The signal is then relayed to a poker-chip-sized receiver embedded in the skull, just behind the ear, which then sends signals into the electrode coil.



BETSY HAYES

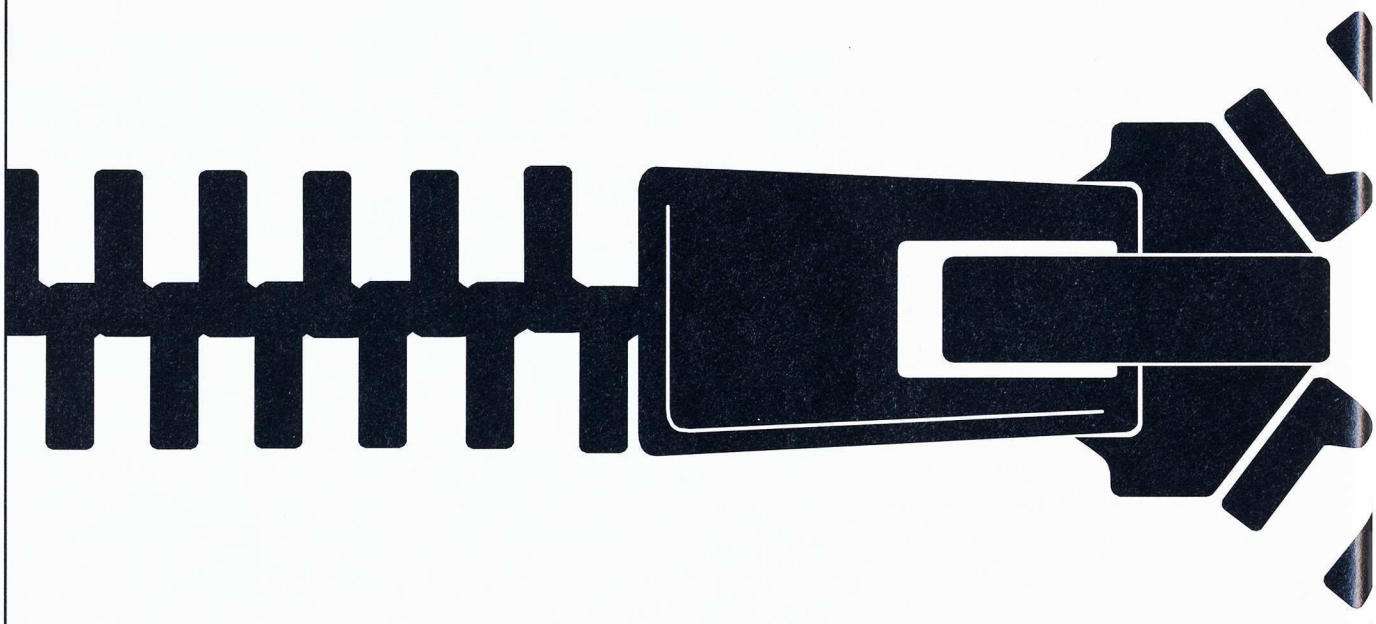
Making the rounds for Med-El at trade shows, Pierschalla has become something of a poster boy for the success of cochlear implants. But not everyone with an implant does as well. According to Bryan Pfingst, an otolaryngologist at the University of Michigan's Kresge Hearing Research Institute, "The majority of patients can use the device to aid in lip reading. [Only] the top 10 or 15 percent can recognize speech well enough that they don't need lip reading."

Researchers still do not understand why some patients do better than others. One problem, says Robert Shannon, director of the House Ear Institute's Auditory Implants Research Lab in Los Angeles, Calif., is the limited ability to customize the implant to a particular patient. "It's as if we were trying to fit people with glasses by giving everybody the same pair," he says.

Shannon says there is still a lot to learn about where exactly to position the electrodes, what the best stimulus levels are, and how to provide the brain with the information it needs to recognize speech. To demonstrate the point, Shannon has developed a computer program that simulates what it sounds like to wear a cochlear implant. Simulating a one-electrode device, a recording of Shannon's voice is unintelligible. Two channels is almost as bad, but when he plays the message using four channels every word can be made out. Shannon argues that "If we could get every implant patient to fully utilize all 22 electrodes, they would have almost normal hearing."

Shannon notes that people who have learned English as a second language often cannot decipher the four-channel message—evidence, he says, that implant success depends heavily on a patient's speech skill prior to becoming deaf. According to John Middlebrooks, an auditory physiologist at the University of Michigan's Kresge Hearing Research Institute, this is one factor leading physicians to implant children as young as nine months old who are born deaf. "In the early years the brain is primed to pick up a language and maybe these children will pick up electronic language," Middlebrooks speculates.

Regardless of where the technology goes from here, "The current implant is a miracle," Middlebrooks says. "We've got patients who formerly could not hear anything at all and now many of them can talk on a telephone...That's really very good."



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fire" to move from hand-held electrodes to an actual implant. The know-how gleaned so far about how to stimulate retinal nerves is now being turned into a prototype device by a collaborating team led by Professor of Electrical Engineering Wentai Liu at North Carolina State University (NCSU).

ALL THE RESEARCHERS INTERVIEWED for this story emphasized that the results at Johns Hopkins, while exciting, do not mean blind people will be able to read newspapers, or even recognize a face anytime soon. But, says Ronald Carr, a New York University professor of ophthalmology and retina expert, a retinal implant that could allow some blind people to see light and dark now appears "feasible." Ultimately, they may even be able to perceive enough of the shapes around them to walk without a dog or cane. "Obviously, this is never going to approach what one sees with the human eye," says Carr. "But there's a huge difference between seeing nothing, and being able to see outlines. Anything that could be done is a marked improvement."

John Wyatt, a professor of electrical engineering at the Massachusetts Institute of Technology, says it is precisely because "the standards we need to be useful are quite low" that artificial vision is feasible at all. Wyatt's MIT lab is home to another artificial retina project, which is taking a slightly different approach than the Hopkins/NCSU team.

The effort got under way in 1988, when Joseph Rizzo, a Harvard Medical School neuro-ophthalmologist, approached Wyatt to find out if the engineer could help him build a retinal implant. Wyatt, who had some experience in retinal neurophysiology from his doctoral studies at Berkeley, was initially skeptical. The retina looked like a pretty flimsy circuit board. But his fascination with the eye's circuitry made the project too tempting to pass up, and he has since become more optimistic. Wyatt gives most of the credit to advances in microelectric fabrication technology, which, he says, "open up the ability to make little delicate things that you might be able to put in the eye [and are] the only reason there's any hope of doing this. Without that, it would just be a complete dream."

Although Rizzo and Wyatt have conducted only two human tests so far (both with inconclusive results), the pair think they know what a retinal implant will ultimately look like. The system, says Wyatt, will start by taking digital pictures with a small camera that can mount on a pair of glasses. Off-the-shelf technology that could do the trick already exists in the form of charged couple devices (CCD) found in conventional camcorders, as well as the newer, smaller and more energy-efficient active pixel sensor (APS) technology that debuted with digital cameras.

A small computer would probably be needed to process the image, which would then have to be sent to the implant inside the eye. The wireless system on Wyatt's drawing board uses a diode laser, also mounted in a pair of glasses, to flash the images captured by the camera onto an array of photovoltaic cells built into the front of the implant. The laser beam would also provide power.

The implant itself, according to Wyatt, will be a silicon chip, loaded with transistors, sitting on the surface of the retina. In this "epiretinal" configuration, the side covered with photovoltaic cells faces outwards, while the other face, studded with 100 or more electrodes, would ride right on the retinal surface close to the layer of ganglion cells. The Johns Hopkins/NCSU implant has a similar overall design, except that it uses radio frequencies instead of a laser to transmit data and power.

The researchers plan to treat each electrode as one picture element, or pixel, with which to build an image. To squeeze the most out of each pixel/electrode, Wyatt hopes that changing the electrical current to each electrode will control the intensity of each spot a patient sees. "The idea is to convey various shades of gray, rather than just light or dark," he says. With just a ten-by-ten grid of electrodes, each providing four to six levels of gray, Wyatt says it should be possible to "start making sense of an image, especially if it moves."

However, researchers still don't know if they can control light levels, or even their color. Volunteers in the Hopkins studies, says Humayun, saw "yellow, green, and blue, but we haven't figured out what we're doing to generate those colors." Nor do they know whether they can stimulate vision long-term, nor what the ideal current is, nor what amount of spatial resolution they can realistically hope for. To answer these questions, more sophisticated arrays need to be tested in people.

While Wyatt won't forecast when he and Rizzo will be ready to do that, NCSU's Liu says his group already has the three key elements—camera, external video processor, and an implant with 100 electrodes. Integration is the next step, says Liu, and he predicts that "within a year or two we will definitely have a completed device."

The Johns Hopkins results, while exciting, do not mean blind people will ever be able to read newspapers or recognize faces.

ALTHOUGH THE EPIRETINAL approach appears to be the most advanced, it is not the only retinal repair system. Alan Chow, a Wheaton, Ill., ophthalmologist (and an alum of Wilmer Eye Institute) is working on a "subretinal" implant that he says will require no external camera, power source or transistors.

The subretinal implant, Chow explains, is a collection of microphotodiodes—think of the conventional solar cells that convert sunlight to electricity, except tinier—that will be implanted behind the retina. Chow's idea is that as ambient light passes through the retina and strikes the microphotodiodes, they will generate enough electricity to activate healthy nerve cells. He figures that by electrifying cells upstream of the ganglion layer, his implant will take advantage of whatever signal processing capacity remains in the retina.

Chow's prototype of what he calls the "Artificial Silicon Retina" is 3 millimeters in diameter, 25 micrometers thick, and contains more than 7,000 microphotodiodes. The results of tests in rabbits, says Chow, have been encouraging. "We were excited to find that the *(Continued on page 55)*

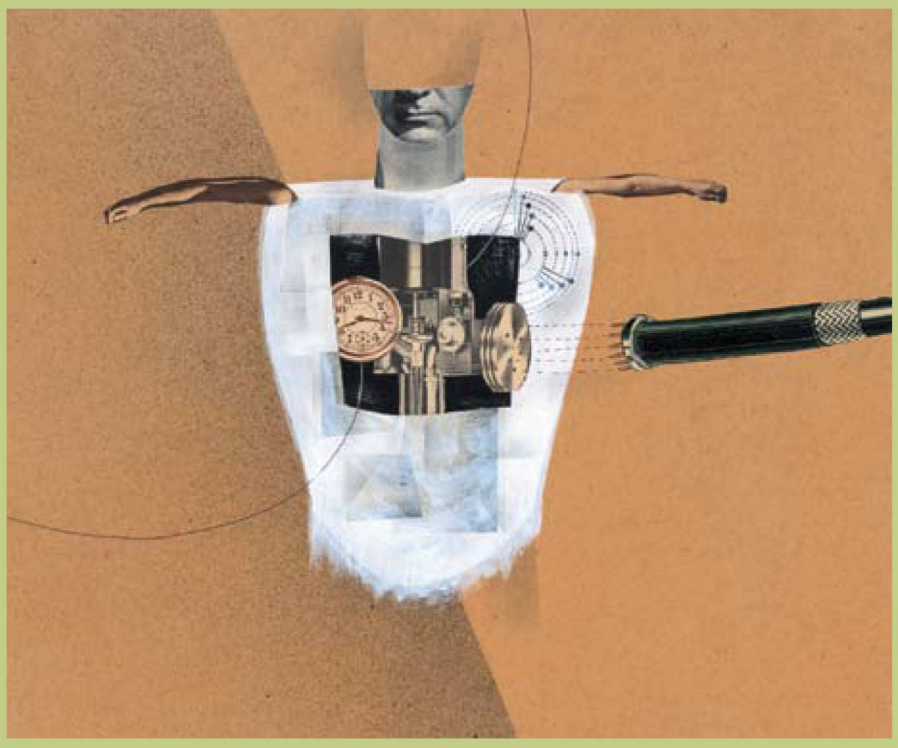
CPR for the Artificial Heart

Reviled in the '80s and forgotten in the '90s, the artificial heart is back and beating. *TR* readers get a rare glimpse inside the company that's developing it. BY ANTONIO REGALADO

At four U.S. medical centers, surgeons, nurses and anesthesiologists are quietly scrubbing in for the return of one of the most vilified medical devices ever conceived—the artificial heart. Each of the four teams was tapped a year ago by Abiomed, a little-known Danvers, Mass., company whose engineers have worked for more than a decade to build a 900-gram electromechanical pump they call the PulsaCor. Surgeons at the Texas Heart Institute and Massachusetts General Hospital, among others, are now practicing putting the synthetic heart into calves. David Lederman, Abiomed's CEO, says they'll be performing the surgery on a human before 2000 is out.

That first patient will, in all likelihood, already be dead. Lederman confides that Abiomed, moving cautiously, will seek permission to undertake a surgical dry run on a brain-dead individual on total life support. Before the doctors and nurses don their gloves, Abiomed's recently convened board of ethical advisors will have spent months overseeing the selection of candidates. What's more, Lederman has devised a complicated credit-sharing scheme to ensure that no single player steals the limelight of what he believes will be a "very visible" event. Even the decision to grant *TR* access to Abiomed's engineers and facilities was a carefully considered media "test case."

The reason for this extraordinary kid-gloves approach is the artificial heart's troubled history. A one-time medical miracle, the device now resides on the short list of technologies American society has labeled "Just Not Worth It." How it ended up there, alongside supersonic planes and nuclear power plants, is a story that dates back to 1982, when a University of Utah surgical team replaced the diseased heart of 61-year-old dentist Barney Clark with a device called the Jarvik-7. Powered by air cables running from a washing-machine-sized console into Clark's chest, the pneumatic pump proved that a mechanical heart could sustain human life. Clark lived for 112 days. The second patient to get the Jarvik-7, William Schroeder, lived for an



amazing 620 days.

If you call it living. Boston University bioethicist George Annas, an expert on human experimentation, says: "I talked to Bill...and he hated the artificial heart. There are things that are worse than death and this was one of them." By the 21st day the device had infected Schroeder's blood. For 420 days he had a fever. For 366 days, he was fed through a tube. Four times, Schroeder suffered strokes as hardened clots of blood that had built up in the heart broke off into his bloodstream. As the Jarvik-7's deadly failings became plain, the media's breakthrough hype turned to condemnation of a cruel and premature experiment.

Now, the concept a *New York Times* editorial once termed "The Dracula of Medical Technology" is back—and some old, thorny questions are back with it. Some say the government's artificial heart program (which paid for Abiomed's R&D until now) is a creature of politics, not science. Others fear another precipitate adventure by gung-ho surgeons. And many question whether a machine will ever amount to anything more than a misery-prolonging understudy for heart transplantation.

In Abiomed's suburban labs a PulsaCor pumps away in a tank of salt water, hardly stirring the plastic balls that float on the tank's surface to stop evaporation. The salt, which mimics the body's corrosive effects on metal, is part of extensive lab testing to determine whether this titanium-and-plastic device can pump 160 million times without failing—enough to move the 2 million liters of blood a patient needs to live for five years.

Like the human heart, the PulsaCor has four valves that gate blood's entrance and exit. But that's where the similarity ends. This heart has only two chambers, instead of four—transparent hamburger-bun-shaped plastic domes clamped onto either side of a metal housing. This sealed, hockey-puck-sized core contains an electric motor that powers a spinning blade through hydraulic fluid. The fluid pushes out against two diaphragms that squeeze blood out of the chambers, through the valves, and into the arteries.

Unlike the Jarvik-7, Abiomed's PulsaCor is designed to fit entirely inside the body, so that the patient can leave the hos-

pital, and perhaps even return to work. To achieve this goal, the system includes an implantable battery and "controller package" containing the electronics that dictate the pump's speed. Each is about the size of a small paperback novel, wired to the pump but implanted in the abdomen. Because the lithium-ion cell can only feed the pump's 12- to 20-watt power demand for about an hour, it will have to recharge continually from a wearable external battery pack. A pair of spiral induction coils—one outside the body, one inside—spirit electrical energy across the skin. It's an odd arrangement but, says Robert Kung, Abiomed's chief of engineering, "any cable going through the skin is an invitation to infection."

Several technical advances since the days of the Jarvik-7 have brought the goal of a totally implantable artificial heart within reach. Better batteries, for example, make it possible to eliminate the external power source that kept Clark and Schroeder tethered to their hospital beds. Faster computer processors have allowed engineers to model blood's movement through artificial chambers and valves, and thereby eliminate spots where blood might pool and clot.

Still, creating a pump that is ultra-reliable, extremely power-efficient and small enough to fit in the 12-centimeter space between the backbone and rib cage has required some engineering stretches all around. Stresses on the flexing diaphragms are high and unabating, but kept shy of the threshold at which cracks can form. The valves are clot-resistant, but not clot-proof—patients will still need to take blood-thinning drugs. The controller package and battery will leak heat into the body, but less than the 2.3 milliwatts per square centimeter that can damage the surrounding tissue. David Myerson, an electrical engineer turned cardiologist at Johns Hopkins University, compares the artificial heart with the Stealth bomber: "Both are engineering outliers. It flies, but it takes every trick you've got."

The engineers who have worked on artificial hearts have had 35 years to learn some of these tricks. The National Institutes of Health (NIH) established the Artificial Heart Program Office in 1964 at the urging of Baylor College of Medicine heart surgeon Michael DeBakey. At that time, the advent of heart transplantation was three years away and patients whose hearts failed faced certain death. Many thought a mechanical replacement would take only a decade to develop—in the age of the Apollo mission, pushing blood through a pump looked eminently doable.

"The original expectation was that you could take existing components and put it together. That turned out to be a false assumption, " says John Watson, director of the NIH's National Heart, Lung and Blood Institute's (NHLBI) office of bioengineering, which now funds the artificial heart. Up close, the project was a hydra, with unexpected materials, power and design challenges sprouting everywhere.

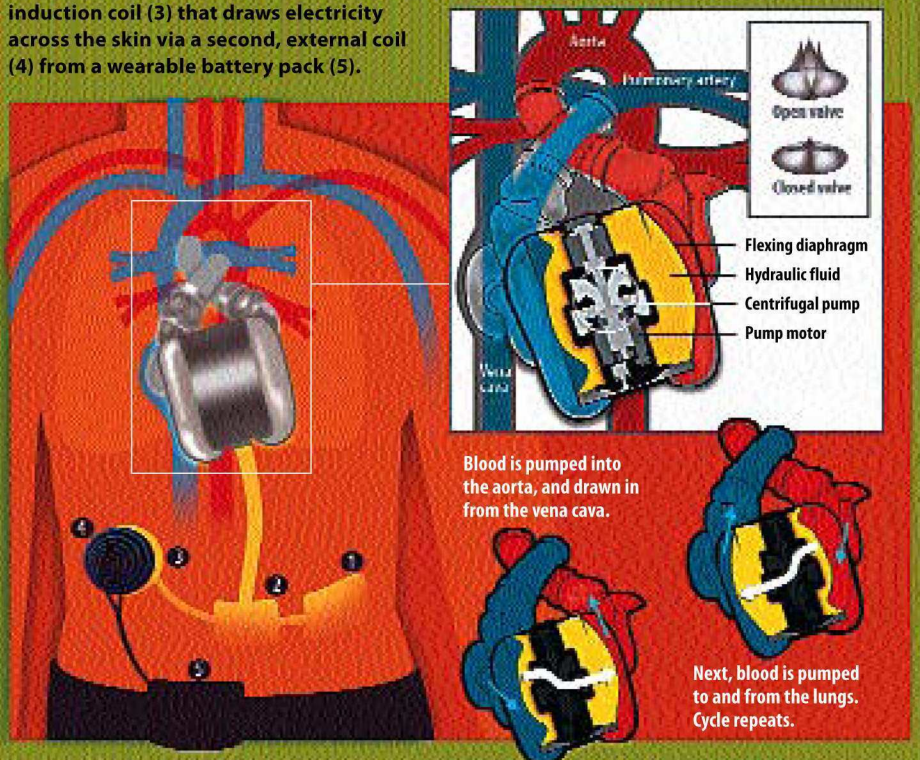
Technology wasn't the only problem. "The symbolic meaning of the human heart seems to carry people away, and blind those involved to what the obstacles are," says Renée Fox, a medical anthropologist at the University of Pennsylvania. In her 1992 book *Spare Parts,* Fox chronicled how the combination of technological shortcomings and surgical zeal led to the Jarvik-7 fiasco.

Since the '80s, the artificial heart has struggled to survive—and has gotten caught up in a battle between politicians and NIH leaders. In January 1988, spending legislation required NHLBI to award $22.6 million to four contractors (including Abiomed) to design and build a totally implantable artificial heart. NHLBI officials, citing inadequate technology, canceled the contracts a few months later, only to reinstate them when Sens. Ted Kennedy and Orrin Hatch (both of whom had constituents working on the project) intervened. Since then, the program has been moving ahead with little fanfare—but under suspicion that politics, rather than science, is

Designing an artificial heart boils down to a numbers game—engineers must balance tight tolerances and high stakes.

ABIOMED'S ARTIFICIAL HEART

Inside the sealed core of Abiomed's heart is a centrifugal pump that alternately pushes hydraulic fluid against each of two flexible diaphragms, forcing blood out of the adjacent plastic chambers. Also implanted are: a lithium-ion battery (1), electronic controls (2), and an induction coil (3) that draws electricity across the skin via a second, external coil (4) from a wearable battery pack (5).



BETSY HAYES

driving it forward.

By now NHLBI has thinned the field from the original four to just two teams: Abiomed and Pennsylvania State University (whose heart is similar to Abiomed's in conception, but different in detail). Each team has received approximately $13 million from NHLBI so far, placing them ahead of less-well-funded efforts at universities in Europe and Japan. In 1997, Lederman says, his technical staff and advisors concluded it was time to start putting Abiomed's own money behind the project, separating it from the academic pack and moving ahead of the NHLBI schedule (at Penn State, researchers don't expect clinical tests before 2001). In 1998, Abiomed poured $10 million into the PulsaCor project, and this year Lederman expects to spend even more.

For the time being, Abiomed doesn't have any commercial competitors. The artificial heart's daunting engineering challenges, combined with its troubled public image, says Victor Poirier, CEO of Waltham, Mass.-based Thermo Cardiosystems, mean that "the only reason people have continued to work on the artificial heart is because the government paid for it." Thermo dropped its own program years ago and, along with most of the field's other players, has turned its attention to a simpler type of implantable pump known as a left ventricular assist device (LVAD), which aids a weak heart rather than replacing it.

The Food and Drug Administration (FDA) has already approved the use of the LVAD as a temporary "bridge-to-transplant" that helps patients in need of a human heart hold out until a donor organ becomes available. Bridge-to-transplant would be an obvious initial application of a total artificial heart, but because of ongoing negotiations with the FDA, Lederman won't say if this will be the first use of the PulsaCor. Ultimately, he says, Abiomed plans to prove the artificial heart's mettle as a permanent implant for the 315,000 Americans that he estimates die every year from sudden heart attacks and other types of acute heart failure that leave no time for transplants. "That is the bulk of patients that we have to deal with," says O. H. Frazier, a top scalpel at the Texas Heart Institute and longtime Abiomed collaborator. "We had a 40-year-old who came in last night with a [heart attack] and basically his heart was destroyed. The only thing that could have saved him was a total artificial heart."

Will that 40-year-old really be a typical artificial heart recipient? Opinions differ. Mehmet Oz, a surgeon at Columbia Presbyterian Medical Center, thinks the device will find a much more limited role, primarily as a replacement when a transplant recipient rejects a donated heart and isn't eligible for another. Others are even less optimistic. "I have some doubts about how well it will do as a permanent implant," says DeBakey. "History tells us this is very difficult."

Whatever their degree of skepticism, all observers agree that only human tests will yield answers. Lederman has promised tests on people will begin before the end of next year. As *TR* went to press, however, Abiomed engineers were still tweaking the heart's final design; the FDA will require Abiomed to run some 12 to 20 units in the lab for up to one year with few or no mechanical failures before human studies can get under way.

And though Abiomed's animal tests look promising, the transition from healthy calves to sick humans presents many unknowns, says Richard Smith, head of the artificial heart program at the University of Arizona. How will human skin react to the electricity-conducting coils, for example? "We are going to have to learn the way we always have learned—which is the hard way," Smith says.

That view is widely shared, and Alan Snyder, who heads the engineering team working on Penn State's heart, warns that the public should have realistic expectations. He notes that even patients who have had only one heart valve replaced with a mechanical substitute have some chance of stroke. With four synthetic valves, he says, "you have to realize that things will happen to these patients that we wish wouldn't."

At Abiomed, Lederman continues to do all he can to make history without repeating it. But no amount of technical care or ethical caution, advisory boards or media test cases can say for sure how the PulsaCor will fare in human testing. "Sooner or later," Frazier says, "we will have to move forward with some uncertainties still."

eye tolerated the chip very well, and it was able to stimulate the remaining cells to produce signals that seem to indicate that vision was being produced," says Chow. But, he acknowledges, "while we know that some form of vision is being produced…we won't know what is seen until we put this into a human." He estimates that human tests could occur within two years.

Chow, who comes from a family of high-tech entrepreneurs, has raised $2.5 million from venture capitalists to fund his startup company, Optobionics Inc., which is developing his device. This success in the venture capital market may indicate that artificial eyes are ready to make the leap from academic research to corporate R&D project. So far, the Johns Hopkins/NCSU and Harvard/MIT teams have been surviving on research grants, but Humayun says "all the groups" are now looking for corporate allies to help with development. In Germany, a startup company named Intelligent Implants is working on a visual prosthesis based on technology from the University of Bonn, one of two retinal implant groups that the German government has funded with $10 million over five years.

Commercial interest is one indication of the excitement that recent progress has generated. Yet researchers in the field are trying hard to balance that excitement with a deep reluctance to raise false hopes among the blind. Today, all the researchers interviewed by *TR* say, there is no way to restore to a blind person anything that even remotely approximates normal sight. But the NIH's Hambrecht observes that the scientific and technological fundamentals have now come into place to change that. Noting that it took cochlear implants about a decade to move from the "crude electrode" stage to commercial availability, Hambrecht puts vision prostheses on the market as early as "10 years from now." Wyatt and Rizzo take a more conservative stance, arguing that "We don't know if it will ever work, and if it does work, we don't know when. Other people may tell you differently, but they don't know either."

Yet it is impossible to ignore the advances made so far—just ask Harold Churchey. Thinking back to the first experiments at Duke in 1992, he remembers vividly how "from the time they put that probe in my eye, I knew they were on the right track. That's the first I'd seen anything in that eye for hard to tell how long." For Churchey, seeing was believing—as it may ultimately be for many others. ◊

TECHNOLOGY UPDATE

Technology that can change the way you live and work.

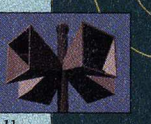
Just take a look at the new products that can help you: **enjoy restful, therapeutic sleep...heat your home evenly and efficiently...spot weather trends before the forecasters...and start a drained battery without opening the hood of your car.** They represent the world's latest technology, and you can try them risk-free with our exclusive home trial.

We knew the storm was coming before the Park Rangers did"

All Hazards Weather Radio provides continual weather and emergency monitoring and has a variety of helpful features.

Until now, there has been no single source for immediate, comprehensive weather and emergency information, available to the public, in advance of TV and radio bulletins. Oregon Scientific, a leader in personal electronics, has created a special radio that is ideal for traveling, as well as for campers, hikers and everyone who needs to be prepared for weather emergencies in the great outdoors. It monitors the U.S. Emergency Alert System and automatically seeks all seven frequencies used by the NOAA (National Oceanic and Atmospheric Administration) Weather Radio system. This network broadcasts 24-hour weather forecasts, weather-related travel conditions and warnings about imminent severe weather conditions.

Automatic alert. In the event of special warning broadcasts, the radio's innovative alert system automatically activates a loud tone



UPDATES AROUND THE CLOCK

- NOAA Weather Radio Network
- U.S. Emergency Alert System
- Federal Emergency Management Agency (FEMA)

Bring a drained battery back to life without opening your hood

The remarkable Auto Starter® eliminates the need for dangerous jumper cables and can provide independent power for a variety of uses.

Imagine this...after a long flight home, you arrive at the airport parking lot, get in your car and turn the key. Nothing happens, not even a click. Guess what? Your car battery's drained. It's cold, dark and you're alone. Do you flag down a stranger and hope he has jumper cables? Do you walk back to the airport, phone a tow truck and wait? No...you simply reach into your glove box and take out your Auto Starter®. You plug it into your car's cigarette lighter and, in a matter of minutes, you're on your way.

A good start. These days, cars have complex electrical systems which increases the risk that someday you'll find your car's battery drained...no horn, no lights, not even a click from the solenoid. Before Auto Starter, you either had to call a tow truck or try to get a jump from another vehicle. Jumper cables, even heavy-duty ones, are dangerous and involve getting under the hood. Plus, there has to be another car around to provide the jump. If the cables are not connected correctly they can damage your car's expensive electrical system or, even worse, cause an explosion. With Auto Starter, you don't need a jump—you don't even have to open the hood. You simply plug the unit into the cigarette lighter, wait a few minutes and you're on your way. Leave the unit plugged in for 30-120 minutes while driving and it recharges automatically.

The five-amp sealed alkaline battery operates under extreme temperatures, from sub-zero to 120 degrees. It is less than eight inches long, so it stores easily in your glove box. Once it's charged, Auto Starter will retain the power to start your car for five years. It is the easiest, most convenient protection you can own.

The Auto Starter eliminates the need for another car to give you a jump, and gives you a portable 12-volt DC power supply!

- *No getting out of your car*
- *No opening the hood*
- *No jumper cables*
- *No tow trucks*
- *No flagging down strangers*
- *Portable power...anywhere*

Portable power. Auto Starter has many other uses. It's an independent 12V DC power supply that can operate TVs, radios, cellular phones and laptops. Almost any appliance that runs off of an adapter can operate independently with Auto Starter.

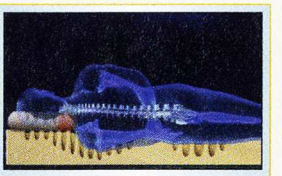
Auto Starter also makes it easier to work on your car. Plug it in before you change the car battery, and you won't have to reprogram your car's clock, radio or alarm system. You wouldn't think of driving around without a spare tire—why not have a spare battery and alternator that fits right in your glove box?

Try it risk-free. Considering the cost of a tow, Auto Starter will pay for itself the first time you have a problem. This product is backed by a one year manufacturer's limited warranty and Comtrad's exclusive risk-free home trial. If you are not fully satisfied for any reason, return it within 30 days for a full refund, "No Questions Asked."

"For years I had trouble sleeping restfully—now I know the problem was in my mattress!"

NatureSleep™ Platinum features comfort zones that match your body's shape and promote restful, therapeutic sleep.

Traditional mattresses leave your lower back and legs unsupported and hinder proper circulation. Even expensive waterbeds, which are supposed to distribute weight evenly, fail to support the body properly. Your spine arches downward, in a position specialists refer to as "hammocking," causing excessive strain on the back. Scientists and doctors agree that the ideal position is a neutral body posture in which the different parts of the human body are supported individually and evenly. This is the secret behind NatureSleep Platinum, the revolutionary product that turns any bed into the ideal sleep surface.



The distinct comfort zones in NatureSleep Platinum have revolutionized the sleep-product industry. They reduce sleep stress—especially strain on the spine—and cradle those areas of the body prone to increased pressure.

Scientific solution. Anatomic Concepts, a medical products research and manufacturing company, has designed the ultimate mattress pad. Using research originally

and a flashing red LED indicator. If the radio is in silent standby mode, it even turns on the speaker. Emergency bulletins might include alerts for tornadoes, hurricanes, earthquakes, ice and snow storms, thunderstorms and other severe weather as well as other emergencies that require immediate public notification.

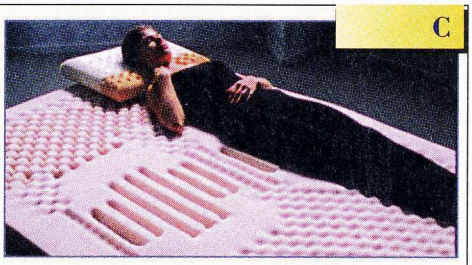
Important features. The radio incorporates a variety of special features geared for outdoor use. These include a built-in analog compass, ambient temperature display and an audible/visual Freeze Warning Alert. The digital display incorporates a clock with alarm and snooze controls. A switch lets you turn the speaker to ON or MUTE, or you can set the unit to stand-by mode. The unit's water-resistant case is rugged and durable, and there's even a built-in belt clip and desktop stand. Its compact, lightweight design makes it ideal for almost any situation, and it operates on 3-AA batteries.

Try it risk-free. The All Hazards Weather Radio comes with a one-year manufacturer's limited warranty and Comtrad's risk-free home trial. If for any reason you are not satisfied, simply return it within 90 days for a full refund.

B

conducted for hospitals, this innovative company developed an effective, affordable way to transform any mattress into a specially-designed sleep surface that closely matches the shape of the human body. It features a patented five-zone sleep surface that holds the body in a neutral posture and redistributes pressure during sleep.

C



✔ *A unique, high support factor design for more comfortable, restful sleep.*

✔ *Comfort zones match your body shape. Built-in lumbar support reduces spinal stress and backaches.*

Comfort zones. The distinct comfort zones in NatureSleep Platinum have revolutionized the sleep-product industry. They reduce sleep stress—especially strain on the spine—and cradle those areas of the body prone to increased pressure. Until now, only the most expensive and most advanced mattress products featured this degree of technology, but now you can get it without even buying a new mattress.

Installs in seconds. NatureSleep Platinum fits right over your existing mattress, uses normal sheets and turns any bed into an anatomically-correct sleep surface. The five comfort zones have been created using a computer-designed grid pattern and are engineered to accommodate people of all heights and sizes.

Risk-free. Try it for yourself, it comes with a one-year manufacturer's limited warranty and Comtrad's exclusive risk-free home trial. If for any reason you are not completely satisfied, return your purchase within 90 days for a full refund, "No Questions Asked."

The efficiency of ceramic warmth combines with oscillation to create the perfect heater...

D

This compact heater uses a genuine ceramic heating element and an oscillating fan to eliminate cold spots and provide intense warmth throughout an entire room!

If you could build the perfect heater, what features would it have? A safe, yet effective, heating element? A thermostat that would let you select a desired comfort level? An effective way to disperse the heat throughout an entire room? Safety features like automatic tip-over and overheat protection?

Royal Sovereign recently unveiled a remarkable new heater that combines a ceramic heating element with a solid-state thermostat and an oscillating fan—its called the RST-1200 Oscillating Heater.

Ceramic advantage. The RST-1200 utilizes a genuine ceramic heating element. Ceramic elements are known to be a very efficient and effective heating method. Ceramic heaters do not burn air—therefore, they do not cause any odors or produce any unwanted side effects. Even more important is the fact that the RST-1200 does not get hot to the touch—so it is not a fire hazard.

Control your climate. The RST-1200 has an electronic thermostat that lets you choose your own comfort level. Simply set the dial to the appropriate temperature, and the RST-1200 will automatically maintain that comfort level. It provides even, uniform heat—without irritating hot/cold cycles.

Spread warmth throughout a room. The RST-1200 oscillates over a range of 70°. A high-velocity fan disperses the intense warmth resulting in even distribution of the heat. The RST-1200 will eliminate cold spots, even in those rooms with poor ventilation!

The oscillating difference.

The RST-1200 is unlike ordinary space heaters. Because it oscillates over a range of 70°, the RST-1200 spreads the warmth created by its genuine ceramic heating element evenly throughout your room, eliminating cold spots. And with its solid-state thermostat, you can set a specific temperature, and the RST-1200 will maintain it effectively and efficiently.

Safety features. The RST-1200 may be the safest space heater you can buy. Its cool-touch cabinet prevents the RST-1200 from being a fire hazard. The RST-1200 also has built-in, automatic overheat and tip-over protection. The unit will shut off if tipped over, airflow is blocked or anything is spilled on it. A red safety light indicates that the unit has shut itself off for some reason. The RST-1200 is so safe you can let it run 24 hours a day, worry-free!

Try it risk-free. The RST-1200 Oscillating heater is backed by Comtrad's risk-free trial. Try it, and if you are not completely satisfied, return it within 90 days for a full refund. It also comes with a one-year manufacturer's limited warranty.

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HUMACHINES

BY REBECCA ZACKS

Dances with Machines

Artist David Rokeby builds machines that watch us, make music with us, speak to us and free-associate on our behalf.

THE MOVEMENTS OF THE LANKY MAN ON THE VIDEOTAPE MESH PERFECTLY with the undulating rhythms and cascading tones that accompany his dance. As the music swells, his gestures grow pronounced and emphatic; as the sound dwindles to the pulse of a synthesized bass or the flutter of an electronic clarinet, his motions diminish to the twitch of a hand or the slow sweep of an arm. The choreographer, it seems, must have worked closely with the dancer and the composer to make such a seamless piece. The reality is more complex: This dancer is, in fact, also choreographer and composer, choosing his moves on the fly while simultaneously making the music to match in an intimate collaboration with a video camera and a homemade computer system.

PHOTOGRAPHS BY RICK CHARD

Sprawled shoeless on the living room floor in his Toronto home, 38-year-old David Rokeby watches the 28-year-old version of himself on a small TV set. Though his worn jeans, wire-rimmed glasses and only slightly scruffy hair make him look like the math professor his parents wanted him to be, Rokeby has instead become an internationally known interactive artist—his multimedia installations invite gallery goers and exhibition attendees to become active participants in the artistic process.

In language that shifts easily between the professorial and the poetic, Rokeby explains both the technology and the artistic intentions behind his work. In many ways, his career sounds like that of a researcher. Rokeby thinks of each of his installations as an experiment; observing the hundreds of thousands of people who have participated with his pieces has given him an invaluable opportunity to learn about humans, machines and the very complicated relationships between them.

Through these artistic explorations, Rokeby has begun to understand how people's interactions with computers change as technogadgetry becomes more and more common. And he has uncovered some ways that machines can subtly distort human perceptions. After years of investigating such ideas, Rokeby worries that our increasing interaction with the Internet and "intelligent" technologies might cause us to devalue some of the attributes that make us human. So while others work toward a transparent interface between person and machine, Rokeby aims to expose the quirks, foibles and rough edges of that relationship. "Because I've programmed a lot, because I've built computers, I know what it's like to write a program and then watch people deal with it, and watch how my decisions change people's experiences," says Rokeby. "For me, it's important that I somehow articulate the importance of that act."

ROKEBY PLAYED THE VIDEOTAPE OF his dance on a sunny January afternoon to demonstrate his best-known project: *Very Nervous System*. The name is an umbrella term for an ongoing series of installations—the project's technological roots date back to some fiddling around with light sensors and a synthesizer that Rokeby did in the early 1980s. Over the years, Rokeby has used the technology behind *Very Nervous System* not only in his artistic endeavors, but also to support them; reduced to its initials, VNS is an image-processing device he builds and sells to performers, composers, researchers and other artists.

What VNS does, essentially, is translate the motion captured in a live video image into a digital signal. That signal can, via a Macintosh computer, drive electronic equipment such as synthesizers, video players and lights—all in real time. In a typical *Very Nervous System* installation, a body moving in the camera's field of vision becomes an integral part of the work, triggering and modulating sounds or other effects.

Rokeby develops software and hardware for projects such as *Very Nervous System* with little outside help, and no formal technical training. As a teenager growing up in southern Ontario in the 1970s, he taught himself programming in order to indulge a fascination with electronic music and computer graphics. At 19, with an offer on the table for a lucrative but uninspiring job in data processing, Rokeby instead embarked on a "five-year plan"—he would focus on the things that interested him and avoid those that "smacked of career." If it didn't work out, he figured, he could always go back to school and get a computer science degree.

After a stint at the Ontario College of Art, almost five years to the day after he hatched his plan, Rokeby received an invitation to show his work at the Venice Biennale, arguably the world's premier art show. The list of his artistic honors has grown steadily since.

Rokeby isn't the only artist exploring the gray area between the body, the mind and the computer *(see "Virtual Plants," p. 62)*, but he began doing this kind of interactive work long before most of the other artists currently on the scene, says Finnish media scholar Erkki Huhtamo, a visiting professor in the department of design at the University of California, Los Angeles. What's more, Huhtamo says, Rokeby is one of few to have constructed his own technological tools. "He's wonderfully capable of doing that," says Huhtamo, "but on the other side he has applied those tools for various artworks—a career that combines these two sides meaningfully and interestingly is rather rare."

Virtuosity in both technology and art has given Rokeby a unique perspective on the evolving ways people relate to machines. Audiences of the early installations, shown at a time before many people used much computing power outside arcade video games, were "more open to

the raw experience," Rokeby recalls. They focused on the physical, and felt as though they were bumping into invisible objects that made noise. As time went on, though, people became more interested in the "gee-whiz" technical aspects of the installations, and in tying the experience into a rapidly expanding computer culture.

But even as PCs became ubiquitous and "virtual reality" and "interactive media" attained buzzword status, there was an ecstatic quality to how people reacted to the piece. "*Very Nervous System* is very exciting," Rokeby says. "To show it is very satisfying on a certain level because people love it, and come up to you and tell you that it's brilliant and fabulous and it has changed their way of looking at something." But Rokeby began to worry that his work was *too* exciting, that people were so blown away by the real-time physical experience that they weren't stopping to ask the questions he had hoped they would: "'What happened between me and the machine? What does that mean for my relationship with my word processor?'"

To Rokeby, the answers to these questions have implications far beyond artistic concerns. He noticed that people tended to credit *Very Nervous System* with more than its fair share of responsibility for certain effects; they might, for example, synchronize their movements unconsciously to a particular preprogrammed rhythm in the mix but believe it was the technology that adjusted to them.

"Given people's general sense that machines are very smart," Rokeby says, "they have a strong tendency to attribute the smarts to the machine, even if it's their own smarts reflected back." Rokeby believes that as interactive technologies, particularly the Internet, begin to play a central role in communications, commerce and civic activities, "the sense of where the control is and where the intelligence is becomes more significant, more politically and socially important."

TO GET AWAY FROM THE DISTRACTING excitement of *Very Nervous System*, in the 1990s Rokeby began working on pieces that were less physical and lacked the frenzied feedback between audience and computer. In 1995, he started showing a piece that turned his early installations inside out, giving audiences the chance to watch the computer's image-processing operation as it happened and to see what the machine had been seeing for all those years. "One of the things that was always weird about *Very Nervous System*," Rokeby says, "is that it *is* a surveillance system, but no one ever felt threatened by it—people didn't feel like they were being watched."

So in *Watch*, Rokeby created an overtly voyeuristic experience. Video projectors shine two images side-by-side, each a processed version of a surveillance camera's view of a nearby public space. In *Very Nervous System*, the computer extracts motion from a video signal by comparing one frame with the last and determining which pixels have changed, but that whole procedure is invisible to the viewer. The image-processing techniques used in *Watch* are a dissection of VNS's internal workings. On one side only the things that are moving show up, white ghosts gliding through a black void; the other side shows only what's still, a seemingly normal but frozen black-and-white video image.

To these images, Rokeby adds a soundtrack: The occasional noise of a camera shutter or electronic beeping interrupts soft hypnotic sounds of breathing, a heartbeat and a ticking clock. It's a reminder, Rokeby says, that there might be something wrong with spying on people in this way.

Watch also serves as a reminder of how different the world can look when seen through varying technological lenses. In the early days of developing the piece, Rokeby aimed the camera out his studio window at a busy intersection. The two different video filters—one catching motion, the other stasis—became socioeconomic filters: In one image, members of a vibrant crowd moved swiftly about their business, in the other, panhandlers appeared to be sitting quietly alone on a deserted sidewalk.

Rokeby again draws from art a lesson about the impact of technology on our perceptions. The image-filtering techniques he employs in *Watch* are very similar to those used to compress video for storage or transmission. (Programmers save digital space by recording or sending only the changing pixels in successive frames of a moving image.) The more we use such techniques in daily life, he says, the more we wear inherently biased lenses. Rokeby says he is particularly concerned by the large number of design decisions being made "by programmers in startup companies working on intense deadlines, with very little experience of philosophy and politics."

THOUGH THE INSIGHTS ROKEBY HAS gained through his art may put him in a better position to make such programming decisions, he has no desire to tie himself to his own startup company. He builds and sells only a few VNS units a year, though many more people would like to get their hands on one, according to Todd Winkler, a music professor at Brown University. "In the computer music world, his system is very well known and people talk about it, want to learn about it all the time," says Winkler, who has used his own VNS setup for more than three years in installations, performances and demonstrations. Still, Winkler understands Rokeby's decision to focus primarily on art rather than commerce. "Getting into the business of making little metal boxes that everybody in the world wants could really consume you completely," Winkler says.

On the contrary, what is consuming Rokeby these days is his latest project, *The Giver of Names*. It's a concept that came to the artist almost instantaneously on the day after his birthday in 1990. "The idea was there would be a computer and objects and you could present the objects to the computer and it would talk about them," he recounts. Realizing this seemingly straightforward notion, however, has taken the better part of the decade.

Part of the motivation behind *The Giver of Names* was what Rokeby, perhaps presciently, saw as a shift in the interplay between people and technology. As he wrote in an e-mail quoted in the catalogue

Rokeby aims to explore and expose the quirks, foibles and rough edges of the relationship between us and our machines.

for the 1998 premiere of *The Giver of Names*, in the 1980s it was the body that was "most challenged by the computer.... In the '90s it seems to be the notions of intelligence, and consciousness."

Rokeby worries that as we grow accustomed to such phenomena as intelligent agents on the Internet and computerized phone systems, we may devalue certain human attributes. To talk to that computerized receptionist, for example, we often have to exaggerate and mechanize our speech—the change in enunciation is a "subtle dumbing-down process." So rather than trying to make *The Giver of Names* a flawless facsimile of human thought, Rokeby wanted to leave it rough, exposing the "quirky textures" of a strictly mechanical intelligence rather than using clever programming to paper them over.

In action, *The Giver of Names* is quirky indeed. The installation space is spare: A video camera aims at a black pedestal around which a variety of objects are strewn. Off to one side is a Macintosh G3. Visitors can select objects from the pile, or items they've brought with them, and arrange them on the pedestal; the computer captures an image and processes it, identifying colors, outlines and shapes. The system then begins a mechanical version of free-association, pulling up words that are somehow connected to the details culled from the image. *The Giver of Names*' "state of mind" in this process is a relational database of 100,000 objects, words and ideas.

An object on the pedestal, Rokeby explains, "is like a pebble dropped in a pond of memory, and the associations are like ripples moving away from the initial object and exciting or stimulating different parts of the memory." The words most "stimulated" in this process become the palette from which the computer chooses in forming sentences that appear on the computer screen. At the same time, male and female voices fill the installation space as they utter the words.

Presented with a soda bottle and an apple, for example, the system might pick up on the red of the apple and the shape of the bottle—these would probably stimulate the word "wine," among others, says Rokeby. "As for the sentence, it could be anything from 'The wine spilled' to something completely off the wall like 'Red aliens from inner cities flopped sumptuously on the wine-stained sofa.'"

Early on, *The Giver of Names* tended to talk about war. The system's fixation on generals and grenades prompted Rokeby to consider the fact that many of the databases he used were developed for military-sponsored artificial intelligence and natural-language processing research. "It's kind of interesting," he says, that the tools "used to train artificial intelligences about language will inevitably have a strong defense bias, because the best resources right now were funded by the Defense Department."

Rokeby is the first to admit that such specific lessons aren't likely to be obvious in his artworks, that most people won't listen to *The Giver of Names* talking about a piece of fruit and say, "Gee, I should really think about the effects of military funding on the future of artificial intelligence." But by seeing ourselves in collusion with and in contrast to the mechanical perceiving, thinking and speaking systems that Rokeby builds, we can all begin to think about, as he puts it, "how much of what we do is basically mechanical and how much of what we do does imply something richer and more complicated." And Rokeby takes great satisfaction in the unique intensity with which interactive art allows him to communicate such ideas. Not everyone gets the point of each installation, he says, "but when they get it, boy do they get it." ◊

Virtual Plants and Other (Online) Creatures

Though David Rokeby and other artists who create interactive installations are starting to gain a foothold in the mainstream art world, it's still unlikely that you'll be able to find their work at a museum near you. You can, however, readily find these folks on the Internet, where their combination of computer savvy and artistic sensibility produces Web sites that are well worth exploring. Here's a small sample of what's out there:

Rokeby himself provides an extensive catalogue of his pieces, along with some of his writings, at **http://www.interlog.com/~drokeby/.**

Austrian-born Christa Sommerer and French-born Laurent Mignonneau teamed up in 1992, and now work at the ATR Media Integration and Communications Research Laboratories in Kyoto, Japan. At their ATR Web site (**http://www.mic.atr.co.jp/~christa/**) you'll find images from and explanations of the elaborate virtual ecosystems they've created for installations and Web-based pieces. Sommerer and Mignonneau have built a number of unique viewer/machine interfaces: Audiences can create new plants or creatures and influence their behavior by drawing on touch screens, sending e-mail, moving through the installation space, and even by touching real plants wired to the computer.

Janine Cirincione and Michael Ferraro, both faculty members at New York's School of Visual Arts, founded their design studio, Possible Worlds, in 1992. The company's elegant site (**http://www.possibleworlds.com/**) provides a glimpse both of commercial projects (which include a new animated show for MTV) and of interactive installations—joystick-controlled journeys through surreal computer-generated landscapes populated with quirky characters.

New York performance and installation artist Toni Dove has shown a number of virtual-reality and video-laser-disc pieces. A viewer's gestures drive the sound and images in Dove's interactive movie, *Artificial Changelings,* which tells the parallel tales of a 19th-century kleptomaniac and a 21st-century hacker. Read more about Dove and *Artificial Changelings* at **http://www.funnygarbage.com/dove/**, and be sure to click on the small moving pictures at the bottom of the opening screen for an archive of images from the installation.

The Ars Electronica Center in Linz, Austria, is a home for interdisciplinary investigation of art, society and technology. At the center's somewhat labyrinthine site (**http://web.aec.at/**), you can explore the institution's "Museum of the Future," as well as archives from its annual festival and from the Prix Ars Electronica—an international computer art competition that has had a special category for interactive art since 1990.

Finally, installation artist Stephen Wilson, a professor in San Francisco State University's Conceptual/Information Arts Program, has compiled an encyclopedic list of links on "Intersections of Art, Technology, Science & Culture" at **http://userwww.sfsu.edu/~infoarts/ links/ wilson.artlinks2.html**. From here, you can get to pages on a vast number of artists, events, organizations and areas of research. Wilson's book, *Information Arts,* is due out soon.

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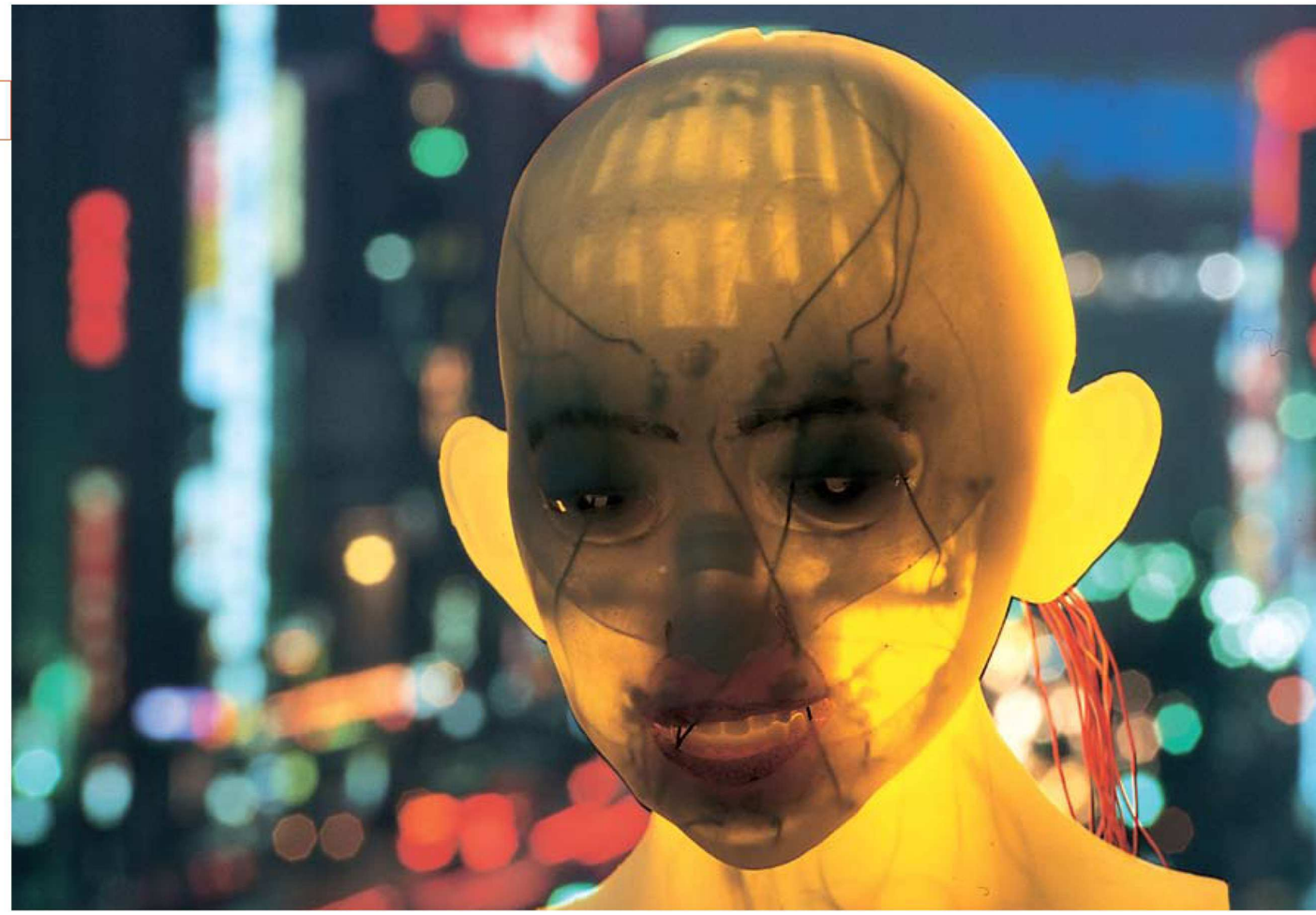
HUMACHINES

BY BOB JOHNSTONE

Japan's Friendly Robots



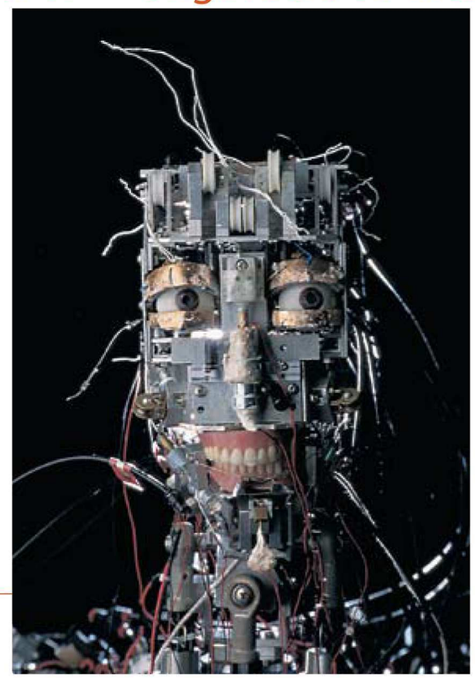
In Japan, a cartoon inspired a generation of engineers to make machines that look—and act—human.

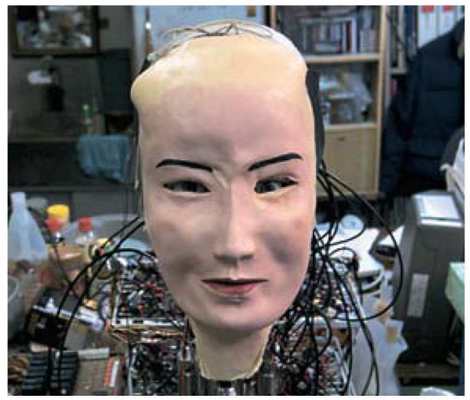
BOLTED ONTO A TWO-WHEELED TROLLEY, WITH A TINY SQUARE HEAD, pink shoulder pads and outsize metal claws, Hadaly-2 doesn't look much like a human being. But behavior is another story: Shine a light in this robot's eyes and it will squint, blink and turn away in a strikingly humanlike manner. Created at Tokyo's Waseda University, Hadaly-2 is among the latest manifestations of Japan's unique obsession with friendly humanoid robots.

Although Japanese technical leadership in the area of mechanical folk dates to the 1970s, "there's been a big burst of energy during the last three years," according to Rodney Brooks, a roboticist at the Massachusetts Institute of Technology.

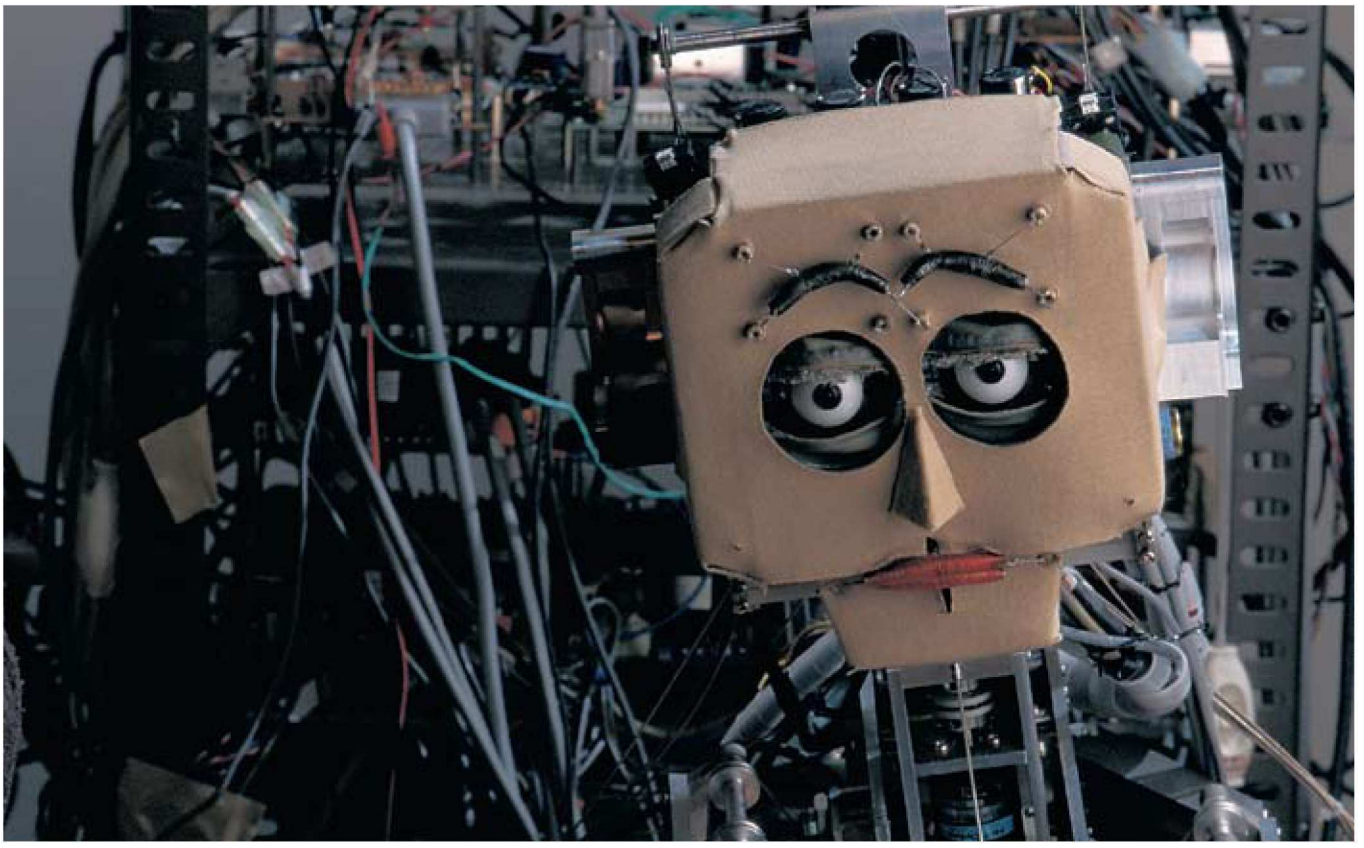
Brooks was one of the U.S. researchers who visited Tsukuba Science City northeast of Tokyo last October for the first International Workshop on Humanoid and Friendly Robotics. There, Waseda engineers wowed crowds with both Hadaly-2 and an ungainly

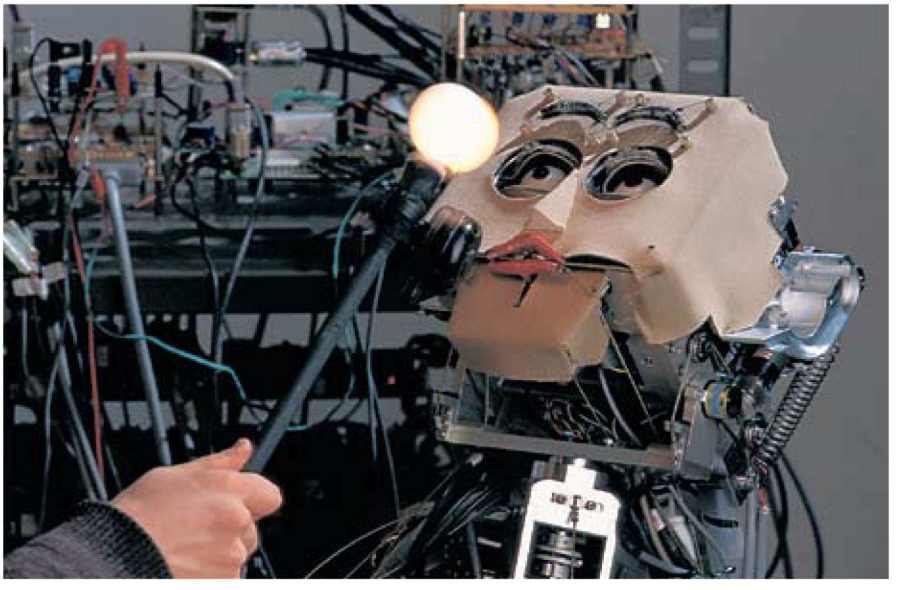
PHOTOGRAPHS BY PETER MENZEL





"Animated-face robot" (left, above) at the Science University of Tokyo shown with and without its skin. A CCD camera in the robot's left eye detects facial expressions of nearby humans. Pneumatic actuator-motors in the face allow it to respond with one of six different expressions. Advanced "shape memory" actuators in the next-generation robot (right) are visible when illuminated by a penlight (top).





WE-3R: (above) The mobile lips, eyebrows and lidded eyes of this anthropomorphic face robot at Waseda University can express happiness, sadness and fear based on sensory inputs. WE-3R can follow a light with its eyes (left) and recoil if struck on the head. The dozens of engineers who work on Waseda's Humanoid Project regularly cannibalize their creations: WE-3R's innards previously belonged to a robot named Hadaly-2.

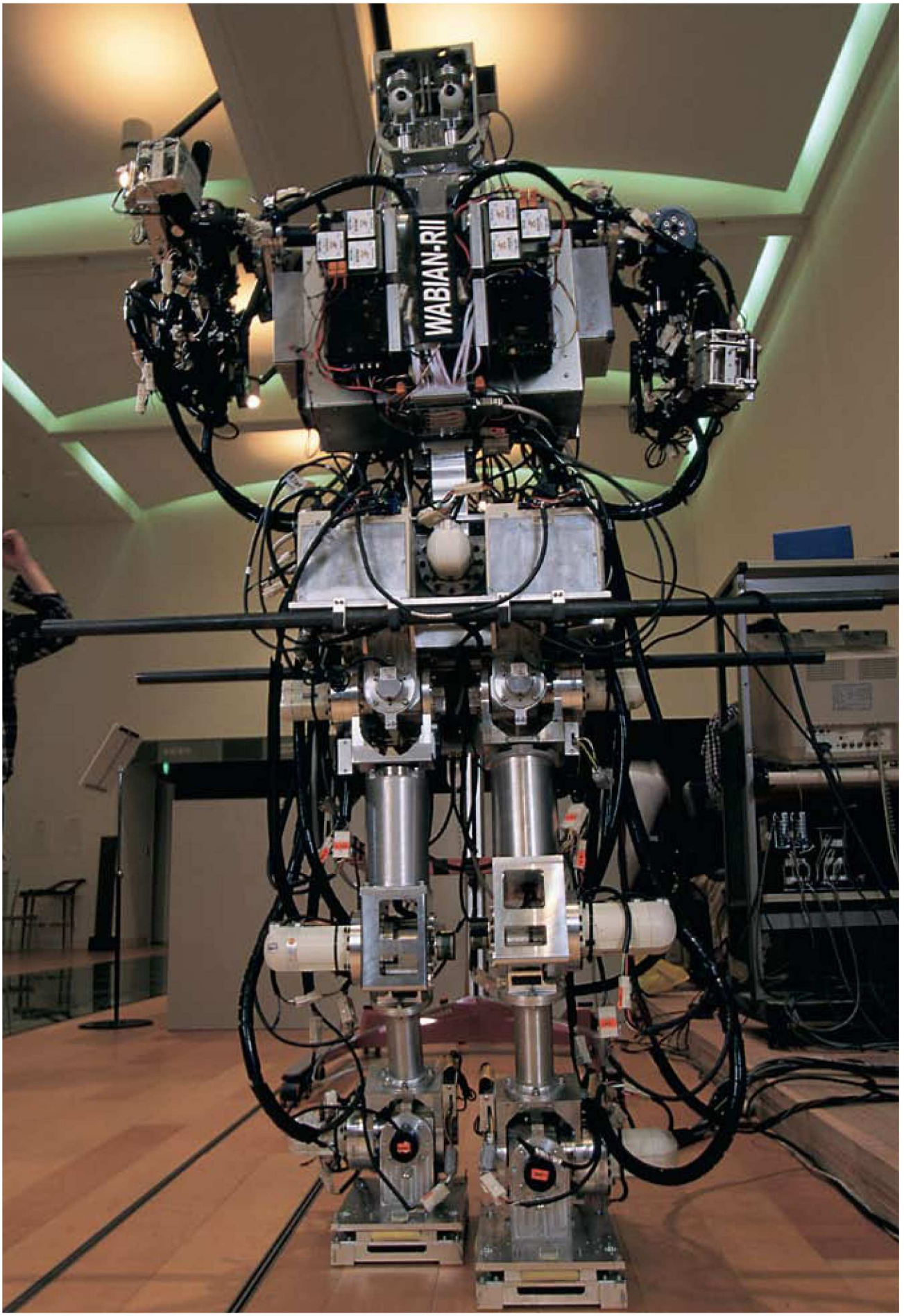
WABIAN-RII: (opposite page) Waseda Bipedal Humanoid-Refined can walk shakily and dance with its human operator. WABIAN is a study in key technologies that will allow robots to support humans physically and emotionally. Applications include caring for the elderly.

bipedal humanoid named WABIAN that can recognize seven human gestures including "Hello," "Good-bye," "Come here" and "Go away." Two dozen presentations from other top universities and big corporate labs revealed a Japanese research establishment intent on endowing robots with the realistic motions, simulated emotions and interpersonal skills needed to move them off the factory floor and into people's homes and offices.

The current android craze was touched off in late 1996 when Honda Motor Corp. unveiled a bipedal humanoid dubbed "P-2." The product of a secret 10-year, $100 million research effort, Honda's 250 kg creation resembles a space-suited astronaut. A backpack full of batteries made P-2 the first humanoid robot able to walk autonomously, without a power or control cord.

Stunning videos of P-2 climbing stairs and giving flowers to young girls caused a drama in the Japanese press and spurred Japan's Ministry of International Trade and Industry (MITI) to launch a five-year national Humanoid Robot R&D Project. Honda will produce a dozen or so copies of a next-generation robot called P-3 for a consortium of university and government engineers to use as a test bed to develop android applications, including entertainment and disaster rescue. The budget for the project's first year—the only figure currently available—is around $8 million.

Japan's big push for human simulacra leaves Western observers with one nagging question, says Australian National University roboticist Alex Zelinsky: "Why?" The answer is simple, say Japanese researchers. They were inspired by a cartoon.


WABIAN-RII

Honda P-3: (above) Inside a classified R&D facility, a technician commands Honda's P-3 android via telemetry. The 130-kilogram, 1.6-meter-tall robot can walk at up to 2 km/hr and climb stairs. A vision system that allows it to navigate around furniture is a step towards Honda's goal of a humanoid robot that can "coexist and cooperate with human beings."

Biped Locomotion Robot: (opposite page, top) At Nagoya University's Fukuda Lab, evolutionary algorithms help robots learn how to walk using minimal energy. This biped's staggering gait is like that of a human toddler—a graduate student prepares a helping hand in case of a stumble. The robot's arms are on the table behind it.

Robot Pets: (opposite page, center) Sensors beneath the fur of a robotic feline named Tama respond to caresses from MITI engineer Takanori Shibata. Automation company Omron, which built the cat, plans a commercial launch pending a reduction in production costs. A robot dog (opposite page, bottom) from Sony Computer Science Laboratories will take "40 years [to] perfect," according to executives.

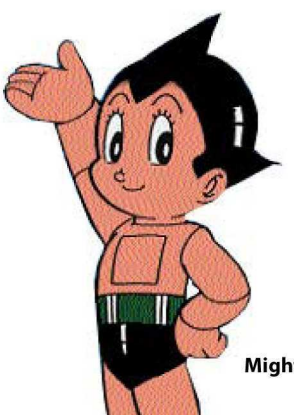
Tetsuwan Atomu, Mighty Atom, the creation of Osamu Tezuka, made his debut in 1951. Mighty Atom stories ran in comic book form for the next 18 years, and beginning in 1963 the hugely popular character also starred in Japan's first animated TV series (later exported under the name of Astro Boy).

In Western culture, robots are typically viewed as slaves that when given intelligence and human qualities will respond by challenging their human masters for supremacy. Think "The Terminator" or the murderous replicants in "Blade Runner."

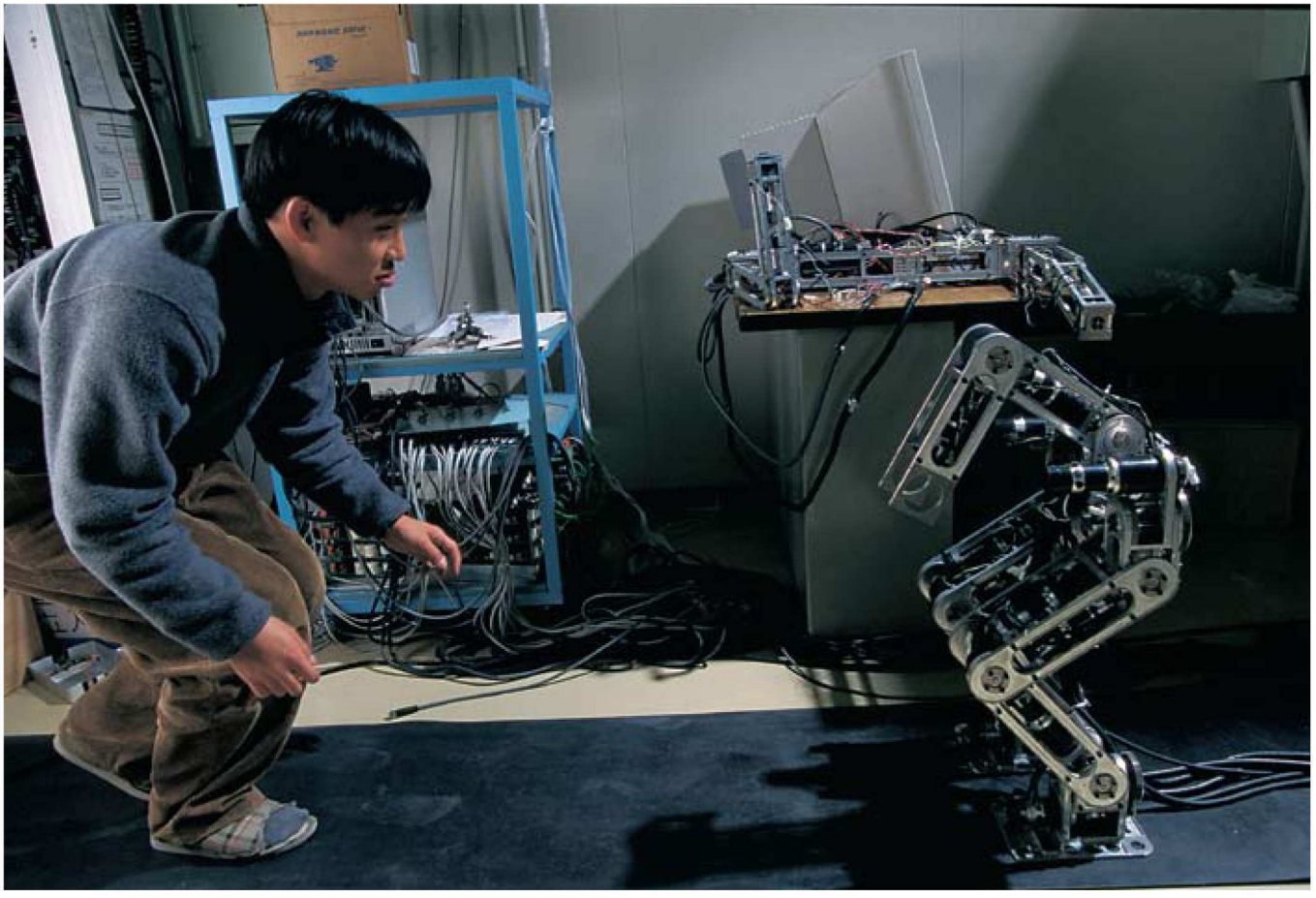
Mighty Atom, by contrast, was decidedly beneficent. Depicted as a little boy with huge eyes and spiky hair, Mighty Atom helped humanity by fighting monsters and bandits in the name of peace. In his exhaustive and entertaining analysis of the Japanese preoccupation with robotics, *Inside the Robot Kingdom*, Fred Schodt writes that Mighty Atom was forever "striving to become more human (i.e., emotive and illogical), and also to be an interface between two different cultures—that of man and that of machine...over the years in the public mind, he—and robots—became linked with a wonderful future that science and technology could provide."

Thanks to Mighty Atom, says Takanori Shibata, a researcher at MITI's Mechanical Engineering Laboratory in Tsukuba, "Japanese people have very positive impressions of humanoid robots; they think humanoid robots always help humans."

While they may take their inspiration from comic strips, Japan's robot researchers are no idle fantasists. Rather, they exhibit a very Japanese emphasis on applications, such as caring for Japan's rapidly aging population. (By early next century, one in four Japanese will be over 65.) "In such a society," Kazuo Tanie and Hideo Tsukune, the co-chairmen of the Tsukuba Workshop wrote in their foreword to the conference proceedings, "we suppose that there are some needs for robots that can support the daily life [of



Mighty Atom



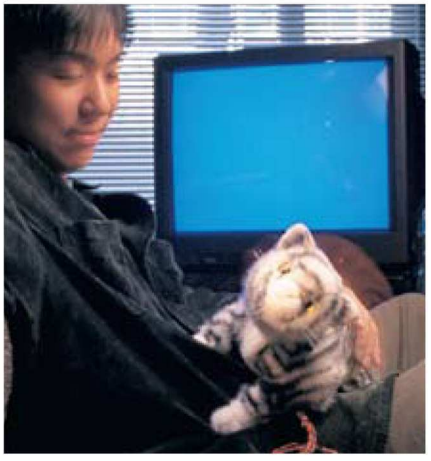
the elderly]." Possible tasks include housework, remote diagnosis via a network, or rehabilitation—such as helping stroke sufferers to walk.

Friendly humanoid robots, Japanese researchers believe, will be best suited to sharing the physical and emotional environment of the home. Take Hadaly-2's bashful blinking. It is part of what engineers with Waseda's Humanoid Project term an "emotional man-machine environment interaction." Launched in 1992, Waseda's project now involves more than 60 researchers in seven labs working on key communication technologies that will permit robots and people to cohabit. In addition to an anthropomorphic head-eye system capable of rapid movement, the Waseda teams are combining voice recognition software and speech synthesizers to give robots conversation skills. At nearby Science University of Tokyo, engineers Fumio Hara and Hiroshi Kobayashi have created a robot whose vision system lets it identify human emotions such as surprise, fear, happiness and disgust. A motorized mask allows the machine to respond with grimaces or smiles of its own.

Friendly robots also come on four legs. Last June, Sony's D-21 laboratory announced that it had constructed a 15-cm-tall robot dog capable of doing cute tricks, such as falling over and getting up again, in response to visual cues from a human operator. Toshoi Doi, Sony corporate vice president and president of Sony Computer Science Laboratories, believes such "entertainment robots" will create "a new industry" for emotionally gratifying mechanical playthings, a prediction that gained credence with the news that two other large Japanese electronics firms, Omron and Matsushita, had come up with robot cats.

Omron's electromechanical feline relies on physical contact rather than vision to interact with people. Via five tactile sensors and three microswitches located on its head and body, the cat can recognize touching, stroking and hitting. "In my opinion, tactile information will be very important in human-machine interaction," says MITI's Shibata, who helped Omron build the robot. Omron, Shibata says, wants "to introduce pet robots as a kind of tool for the healing of the human mind, to give some relaxation to people who interact with the robot."

Mighty Atom would undoubtedly have approved. ◊



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CONVERGYS $224,250,000 Initial Public Offering	eBay $72,450,000 Initial Public Offering	ZEBRA TECHNOLOGIES CORPORATION *has been acquired by* ZEBRA TECHNOLOGIES CORPORATION $206,000,000	E*TRADE *has received a strategic investment from* SOFTBANK CORPORATION $400,000,000	E*TRADE $256,167,500 Follow-on Offering	FLEXTRONICS INTERNATIONAL $150,000,000 8.75% Senior Subordinated Notes due 2007
FARGO Senior Credit Facilities*	HADCO *has acquired* CONTINENTAL CIRCUITS CORPORATION $220,000,000	IHC $100,000,000 4.75% Convertible Subordinated Notes due 2003	Intuit $473,750,000 Follow-on Offering	JDEdwards $417,910,000 Initial Public Offering	Lehman & Hauspie $156,000,000 4.75% PIERS due 2008
LEVEL ONE $115,000,000 4% Convertible Subordinated Notes due 2004	LEVEL ONE *has acquired* ACCLAIM COMMUNICATIONS, INC. $122,000,000	METZLER GROUP $196,250,000 Follow-on Offering	MICRON $500,000,000 7% Convertible Subordinated Notes due 2004	Prominet *has been acquired by* LUCENT TECHNOLOGIES $211,000,000	RAMBUS $37,950,000 Initial Public Offering
real $43,125,000 Initial Public Offering	Save Smart $25,000,000 Preferred Stock	TRINTECH $18,000,000 Preferred Stock $2,000,000 Common Stock	VISIGENIC *has been acquired by* INPRISE CORPORATION $138,000,000	Western Digital $200,000,000 Senior Credit Facilities*	XcelleNet *has been acquired by* STERLING COMMERCE, INC. $220,000,000

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Seeding the Digital Age

COMPUTERS ARE SO FAMILIAR AND UBIQUITOUS THESE DAYS that it's hard to imagine there was a time when they evoked curiosity and dread. But there was—less than four decades ago. Back then most people's only contact with computers was via bills and bank statements; these were big, serious machines.

And make no mistake, "big" was the operative word. Computers in the 1960s were room-sized systems that required teams of engineers to keep them operational. The makers and users of those electronic record-keeping systems would have laughed if someone had suggested their machines might one day be used for education, personal communications or entertainment. After all, computers were getting bigger and more complex every year.

Into this milieu was born MIT's Project MAC—a Department of Defense experiment intended to change the way people used electronic data processing machines. Officially, MAC stood for "multiple access computers" and for "machine-aided cognition"—two phrases describing then-radical concepts. MAC's goal was to bring those ideas together, and make them real.

MAC was the brainchild of Joseph C. R. Licklider, a Harvard psychophysicist who became the first director of the Information Processing Technology Office of the Advanced Research Projects Agency (ARPA). Licklider saw the computer revolution coming long before others did, and he promised MIT as much as $3 million a year (real money then) to make it happen.

ARPA's influence shaped the world of computing, and Project MAC—along with its descendants, the MIT Laboratory for Computer Science (LCS) and the MIT Artificial Intelligence (AI) Laboratory—was a big part of the story. Licklider charged MIT with creating a system that would split the computer's attention between different tasks, allowing multiple people to use a single machine. Such interactive "time-sharing," which later became commonplace, was science fiction in an era when computers ran programs from instructions punched on cards. Project MAC also broke ground with the development of a software system called Multics. Much of the way computers now operate—from their directory-style file structures to the way they use memory—derives from ideas first implemented with Multics.

Research at Project MAC, LCS and the AI Lab has led to many other milestones of the Information Age as well, from spreadsheets to role-playing computer games. LCS also hosts the World Wide Web Consortium, the closest thing the sprawling Web has to a governing body *(see "The Web's Secret Government," TR November/December 1998).*

This spring, LCS is celebrating 35 years since the inception of Project MAC. And because this history is an important part of the genesis of the Information Age, *Technology Review* is publishing two related articles. First, we present a conversation between LCS director (and *TR* columnist) Michael Dertouzos and Microsoft chairman Bill Gates. Rather than the typical Q&A between Chairman Bill and a breathless journalist, this is a dialogue between peers. Under Dertouzos' prodding, Gates confronts the phenomenon of "open source software," which could threaten the dominance of Microsoft Windows. Their vision of the future of the software business may surprise you. Then *TR* Contributing Writer Simson Garfinkel looks at some companies and technologies that have spun out of LCS—one rich legacy of the project that kickstarted the Information Revolution. TR

Titans Talk Tech:

Bill G. and Michael D.

Michael Dertouzos and Bill Gates ponder open-source software and the future of the computing industry.

DERTOUZOS: It is ironic to me that in the United States, the bastion of capitalism, where people have given of their work lives and capital to create a huge industrial economy, we are now asked to surrender the very same factors of production—our labor and our capital—to develop software that will be open and free for all. I do see some qualified benefits to open software, but I wanted to get your views on the big picture before going any deeper.

GATES: Most of the people and companies that create intellectual property will continue to want to get some payment for it, as with any creative area. The beauty of all intellectual property compared to physical property is that there is no marginal cost of production. The world benefits immensely from this, whether it's from a great book or a new drug or a new piece of software. There are fixed costs, so most work will cost something, but for software sold on a high-volume low-price model the price is very small compared to the value.

There's always been a role for open-source software, and there always will be. Free software has been around for a long time. Likewise there is commercial software where the source is easy to access so the pricing and the source availability are two different things. Ideally, software should be componentized enough that you could extend it without having to read and rebuild the source code of the product.

For any software to gain widespread acceptance and use—to be popular with consumers and corporate customers—it has to possess the infrastructure and support that make it efficient and easy to deploy. So just as the car became popular only when there was a network of gas stations, repair shops, dealerships, paved roads and so on, the same is true for software and most other products.

The role of common standards in intellectual property is central here. Thanks to a common operating system standard—Windows—a whole industry got created, one that employs more than five million people worldwide. When both hardware companies and independent software vendors have a common standard to work with, the end result is enormous choice for consumers.

Open-source software's strength is massive customization but this works against consistency. Consumers don't know what to expect when they load the software; corporate customers find it hard to stay current as each version is customized; developers don't get a volume market because there are multiple flavors of the same product.

A lot of software that started out as university software—like browsers—transitioned to become commercial software when customers asked for rich features and broad support. In the case of browsers they stayed free because of the advertising value and

DERTOUZOS: DONNA COVENEY. GATES: KIM KULISH/SABA

additional demand for complementary products that they create.

DERTOUZOS: I agree with you that there is a role for all three—commercial, open, and free software—and add to the list another important benefit of open software: It accumulates for everyone's use code contributed by many programmers. But what of commercial software, that has the potential of becoming a standard for millions of people? To be used widely, it will be given away initially, and sold later when it has taken hold. In the long term, after the software has stabilized and returned its development cost and a good profit, software developers may find it increasingly difficult to charge for it. I suspect that such software, and maybe most software, will, after a commercial period, become very low-cost, and in some cases, even free. Do you think this is likely?

GATES: One of the key characteristics of the software industry is that, because of incredibly rapid technological change, products must be continuously modified to reflect innovations. For example, software will need to change to support speech input, which will be fantastic for users. So development costs are ongoing. With the high-volume, low-cost model adopted by Microsoft and the PC software industry, such costs are spread widely, so consumers pay a very low price to benefit from billions of dollars of R&D.

"There's always been a role for open-source software, and there always will be." –Gates

The key is in value and utility—if consumers get both, they will be willing to pay for them and, if the software is good enough, it will be used widely from the outset. So the world you are describing already exists: Consumers already get an amazing amount of functionality from their software at a very low cost. Contrast the old proprietary computing model, where software accounted for a high proportion of system cost, with the PC model, where software is only a tiny percentage of overall cost. That comparison makes much of today's PC software seem almost free.

DERTOUZOS: In the commercial period, when the software is still evolving, a successful strategy for maintaining revenue is, increasingly, the annual upgrade, which, incidentally, adds to the "feature shock" of users. This practice, together with an evolving Web, suggests that we'll move from buying shrink-wrapped software to simply buying upgrades through periodic downloads at a monthly fee. Do you see Microsoft and other software developers becoming such "service" organizations?

GATES: Regular upgrades are clearly necessary in an industry that is changing as fast as the software business—just as they are in, say, the auto industry. I can't ever imagine a time when software will not continue to evolve in this way. With the high-volume, low-cost model, you have to make the software as attractive as possible to as many computer users as possible, and that means lots of features. And clearly not all of them will be used by every buyer. But in general I think you are right that, in order to "hide" the complexity and adaptability of software from the average user, upgrades will increasingly be carried out transparently and automatically, without users having to do anything.

So rather than having to ensure that your software is always up-to-date, the software will do it for you—you'll wake up in the morning and the latest version of the software will have been installed overnight. To that extent, software will evolve into even more of a service business than it already is, and in the long term there will probably be a move toward a subscription-style model.

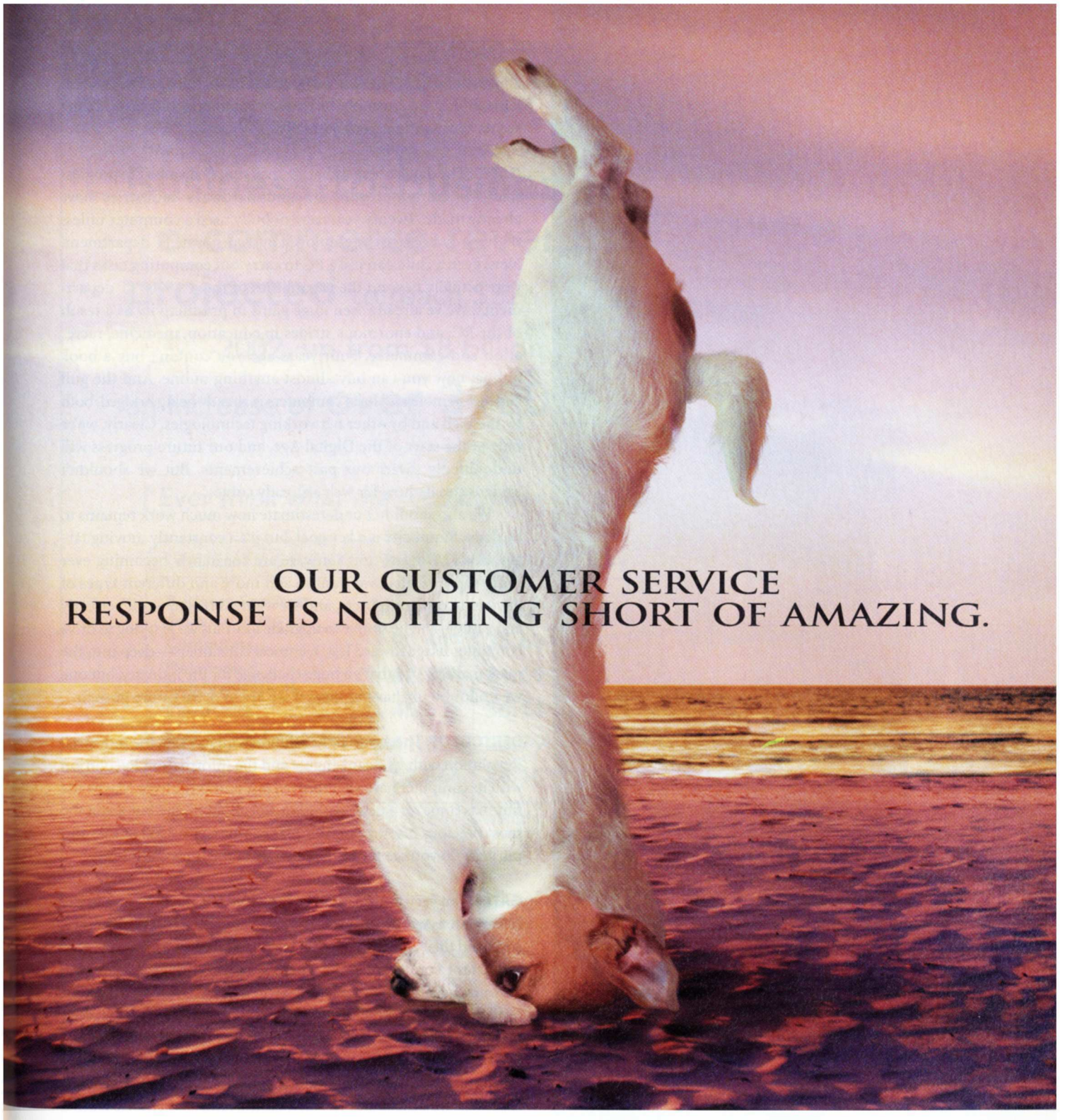
DERTOUZOS: Browsers and operating systems will merge in functionality, simply because people need to have the same commands for dealing with information, regardless of whether it is local or distant. On this, you and I agree. However, we disagree on how to get there: I dream of a system built from scratch that gets rid of layers of old software and brings a new truly easy-to-use metaphor to the Web-centric world, as important as the desktop was earlier. I believe that you want to get there gradually, by upgrading Windows. Recall that the Web itself was created by a small team of people, yet ended up on millions of computers. Could something like that happen here, with a new system that might spring out of nowhere? Would you consider replacing your own baby, ahead of a competitive threat, with a brand-new, simple, super-efficient browser-operating system?

GATES: Whenever a new word is added to a computer language or a new feature to an operating system there is a question of whether it would be better to start from scratch. We actually did start from scratch with Windows NT and I am sure we will do so again. In the meantime, we are evolving every version of our operating system. We have made the browser and HTML the primary display language, replacing the old style help and folder display. There are new operating systems that integrate the browser like BeOS but none have done as much as Windows has.

For every new advance there will be many new competitors, including people who compete with a whole new operating system and people who compete using middleware to run on top of the operating system. If we do our job well, giving people the new capabilities and compatibility, we can make a big contribution.

With Windows running on well over 200 million computers worldwide, we constantly think about the customer base and how we get them from here to there. A lot of the "layers of old software" you refer to do get eliminated—we're constantly stripping out redundant code or replacing it with faster ways of doing what the old code did.

DERTOUZOS: The millions of users of all operating systems and browsers, worldwide, appreciate the need for system stability. Yet the incremental changes that have ensured it have also led to today's difficult-to-use systems—and I mean the systems of all software developers, without exception. Novices and experts alike kneel (I sometimes even cry) as we try to fend off a tangle of intertwined lizards and thousands of moving parts within these systems and the many applications that use them—until we luck in on a fix. We'll have to clean up this mess if we are to provide the true ease of use that will enable people to achieve the 300 percent productivity gains we envision in the 21st century. People will have to rise above battling low-level details, to access the knowledge they need, collaborate with others, customize their systems to their own human needs and automate their own repetitive tasks. I think the time has come



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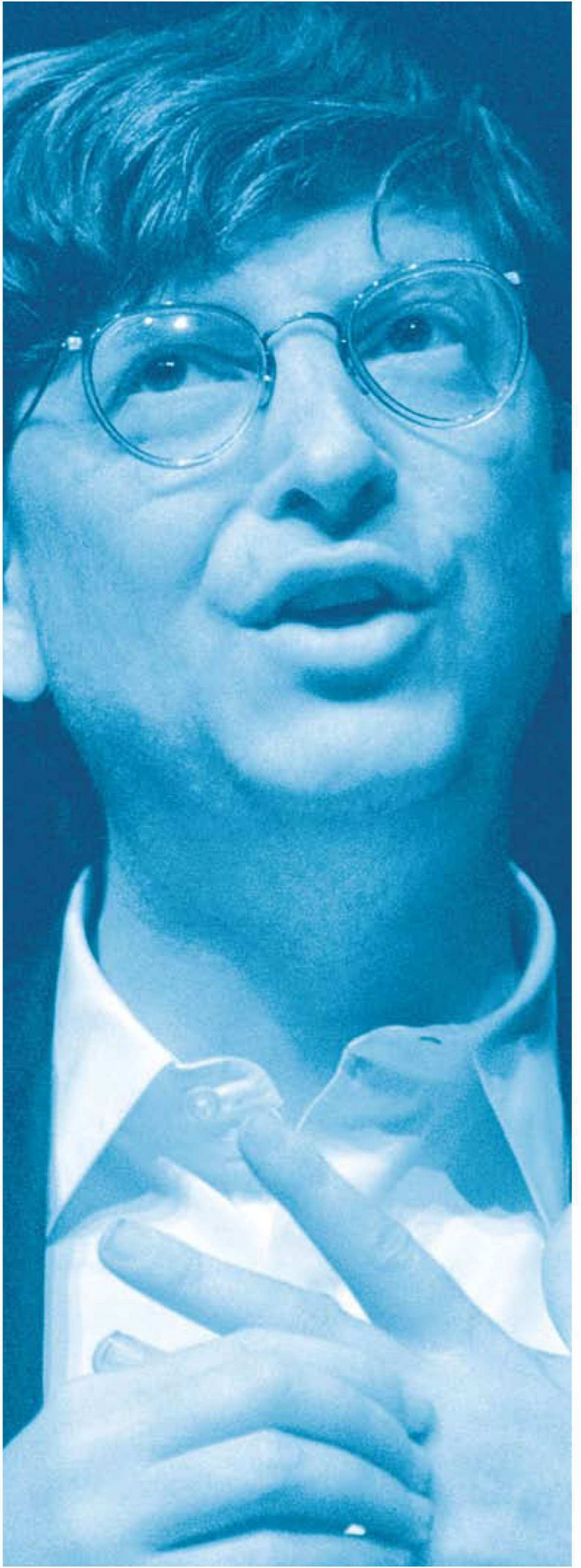

to bridge local and distant computation and support these much-needed capabilities in a new breed of system; applications will then be freed up to use all this new power in medicine, education, business, recreation, commerce and so on. I can't see us getting there incrementally.

GATES: The danger here is that we may simply dismiss the progress that the computer software and hardware industries have already made. Twenty years ago nobody used a computer unless they were a hobbyist or employed by a corporate IT department. Now, even a child can use a PC to carry out computing tasks that were actually beyond the capabilities of those 1970s IT departments. We've already seen huge gains in productivity as a result of the PC, and enormous strides in education, medicine, recreation and commerce. Four years ago you couldn't buy a book online; now you can buy almost anything online. And the gulf between remote and local computers is already being bridged, both by the Web and by other networking technologies. Clearly, we're only at the start of the Digital Age, and our future progress will undoubtedly dwarf our past achievements. But we shouldn't underestimate how far we've already come.

We also shouldn't underestimate how much work remains to be done. Simplicity is a key goal, but it's a constantly moving target. Both hardware and software are constantly becoming ever more sophisticated, we want to add more and different types of devices to our computers, and we want all this to work perfectly and easily—and be simple to upgrade too. Plus we're trying to drive computer usage toward less-technical consumers—deep into the mass market. And that's a huge challenge for the industry, but one we undoubtedly have to meet if we are to drive future growth.

DERTOUZOS: The Agrarian Revolution with its plow, the Industrial Revolution with its steam engine and the Information Revolution with its computer have all improved our economic lives. Maybe the time has come for a new revolution, not about things, but about the most precious resource on this planet—ourselves? What role and purpose do you see for human beings in the Information Age?

GATES: I'm very optimistic about the role of human beings in the Information Age, because this is an era where people—their knowledge, and their ability to put that knowledge to work—will be more important than ever before. There are great dangers to thinking that just because manual labor—whether on the land or in factories—is playing a relatively smaller role in wealth creation, then people are also playing a smaller role. In fact, the Information Age is enabling people who were previously forced to pursue a single means of wealth creation—those, for example, who lived in remote areas had no option but to work on the land—to choose from a far wider range of work. Technology such as the PC, the Internet and cheap telecommunications have brought amazing mobility to the factors of production.

The Information Age has brought people together in even more fundamental ways. The increasing speed and flow of information has opened up closed economies and helped democratize the most repressive regimes. You can close geographic borders but you can't build effective borders in cyberspace. So technology is giving people more freedom, and the power to do more with that freedom. And technology will never replace the wonders of human interaction—no matter how good PCs get at recognizing voice or handwriting, they'll never read body language or smile back at you.

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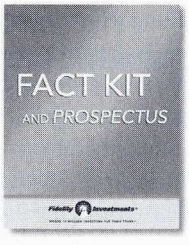

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[1]U.S. Dept. of Commerce "The Emerging Digital Economy," 1998 [2]Life of fund is as of inception date: 6/29/90. [3]Average annual total returns include changes in share price, reinvestment of dividends and capital gains, and each fund's 3.00% sales charge and trading fee. Share price and return will vary and you may have a gain or loss when you sell your shares. All Select equity portfolios have a $7.50 exchange fee and a 0.75% short-term trading fee on shares held 29 days or less. On shares held 30 days or more, the trading fee is the lesser of $7.50 or 0.75%. Fidelity Distributors Corporation.

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DERTOUZOS: I fully share your views and optimism on human beings and the future uses of the technologies we are developing. However, I am concerned about a split that started 300 years ago in the Enlightenment that busted up faith and reason, man and nature, which until that time were united. The liberation of reason caused science to blossom and led to the Industrial Revolution, which made our part of the world wealthy. By now, this split has taken hold, and each of us goes through life in a compartment, labeled technologist or humanist, rational or spiritual, logical or emotional. I don't see the Information Revolution curing this split. It may even aggravate it by increasing our reliance on virtual encounters and machine knowledge. Meanwhile, the world around us is becoming explosively complex with a myriad of intertwined challenges and problems that straddle these divisions and cannot be handled with such partial mindsets. To cope with this new world, but also to enrich ourselves, I believe we need to unite our divided selves and try to become whole again. That's what I mean by a fourth revolution aimed at understanding, beyond things, ourselves. Any thoughts along these lines?

"The angels and the devils are within us, not within the machines we use." –Dertouzos

GATES: If the Information Revolution did lead to a reliance on virtual encounters and machine knowledge, then I would agree with you. In reality, though, the computer is increasingly a gateway to knowledge, to the arts, to new cultures, and so on, that were simply not accessible before. It is creating communities that, far from being mere virtual entities, serve as the foundation for real relationships. So to the extent that the computer can link people with knowledge and cultures and each other more efficiently than any other past technology, it can help push them toward healing the rift you see. But technology is only a tool—and, like all tools, its effectiveness depends on the skill and intentions of the user. In the end, you have to put your faith in human nature. If you think the invention of the book was bad, then you will feel the same way about the changes that are coming. If the book was a good thing, then these advances carry the empowerment even further.

DERTOUZOS: I agree with you on this last point: The angels and the devils are definitely within us, not within the machines we use. And so are our divided selves. That's why I view this as a human problem in need of a human revolution. Speaking of human problems, I believe that left to its own devices, the new world of information will increase the gap between rich and poor people, simply because computers make the rich more productive and hence richer, while the poor are standing still. Do you agree?

GATES: The power of cheap software and cheap computing has brought enormous economic power to millions of people who in the past lacked it. It has helped democratize nations and economies around the world. It is bringing about the death of distance, as high-speed telecommunications link people, companies and countries faster and cheaper than ever before. And while this Information Revolution hasn't yet reached deeply into the poorest regions of the world, it will—look at what is happening in India and China, for example. The Industrial Age did in many ways bypass poorer countries; the Information Age actually gives those countries a chance to compete on equal footing with richer countries. In fact many of the poorer countries have a comparative advantage in that they can now leverage their cheaper labor around the world—not just locally—using the power of the PC, the Internet and cheap telecommunications. The poor are not standing still; they are catching up faster than they ever did in the Industrial Age.

DERTOUZOS: I share the view that the poor could rise out of poverty, by using the new world of information to learn how to read and write, take care of their health, cultivate the land, and acquire language and other skills that they may use to sell services in the information marketplace. However, for this to happen, the poor will need communications, workstations and training—all of which cost a great deal, and therefore cannot materialize spontaneously. The people you allude to, in Bangalore and elsewhere, who deliver software services over the Net, speak English and know how to program. They are but a drop in the ocean of six billion people on Earth, barely 2 percent of whom are interconnected. My point is that all the benefits that we envision will not become available to the poor if we leave the Information Revolution to its own devices. We need to take an active role as individuals, companies and governments of the industrially rich world to help the poor ascend along this path. How can you disagree, in light of all you have done along these lines?

GATES: Unfortunately, the benefits of every new technology tend to trickle down slowly. Even the earliest tools of the communications revolution—the auto, the airplane, the telephone—have yet to benefit some poorer parts of the world. But what will clearly help the spread of information technology is the amazing speed at which computing costs have dropped, along with information technology's ability to break down borders. We're already seeing examples of how cheap PCs can transform companies and government agencies in poorer countries, and the benefits of these changes feed directly to the population. But generally, you are right: companies and individuals in rich countries will have to contribute technology and cash to kick-start a truly global Information Revolution.

I am a big believer in philanthropy, and I'm excited about the impact it can have. I think it is also important to consider priorities. I have chosen to focus on making sure that children in poor countries get access to vaccines so they can live a healthy life. This has to come before making sure they have access to computers. I have put more than $6 billion into my two foundations because of my enthusiasm for taking the great advances in medicine and information technology and giving more people access. We can do some great things here.

DERTOUZOS: I wish other people and organizations would follow your philanthropic lead. And thanks for this enjoyable and informative discussion. ◊

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Michael Dertouzos set the mold by spinning off the computer graphics company Computek and leading "two lives."

Joseph C.R. Licklider, founder of LCS forerunner Project MAC, headed a team that launched Infocom. The company failed; its intellectual legacy lives.

Fountain of Ideas

A reservoir for computing innovation, LCS has provided a haven for startups—and a place for researcher/entrepreneurs to regroup and begin again.

MANY ACADEMICS SEE RESEARCH AS AN END IN ITSELF. AFTER ALL, the purpose of a university is to develop knowledge—not to make a profit. But the researchers who have worked at the MIT Laboratory for Computer Science (LCS) since its inception 35 years ago have shown a keen sense of market potential.

Floating on a secure base of defense funding, the laboratory has over the decades served as a reservoir of technical creativity. LCS researchers have frequently found the Lab a comfortable base from which to launch companies that commercialized their MIT work while maintaining their academic connections.

LCS Director Michael Dertouzos, who started Computek in 1968 to commercialize a graphics device he had invented, sums up the appeal of this dual existence. "I had these two lives," recalls Dertouzos. "When I got bored [at LCS] I went to the company and got stimulated with real engineering. And when I got bored there with real engineering, which was often," he came back to MIT. Computek grew to 120 employees before Dertouzos sold the company in 1977 and returned full time to academia—a pattern that was to be followed by many LCS spinoffs through the years.

Infocom: The Legacy of Zork

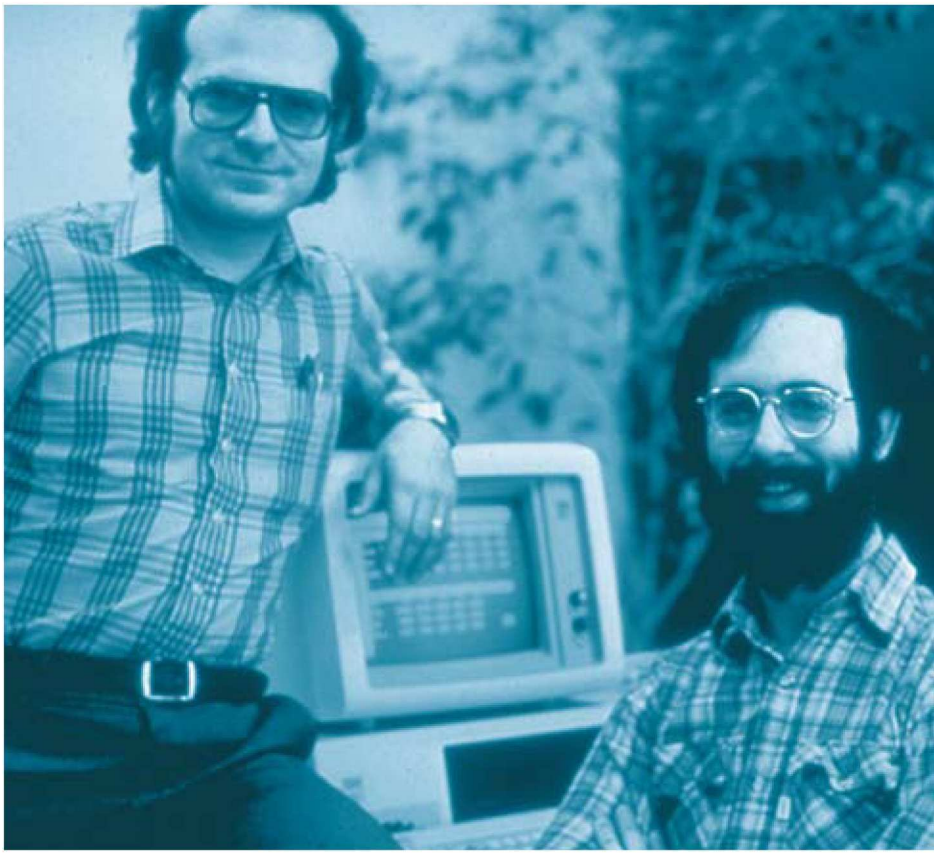
MANY NEW BUSINESSES FAIL, AND THOSE FROM LCS ARE NO EXCEPTION. But while one measure of success is financial, another is the intellectual legacy that a company leaves behind. And along this dimension, LCS spinoffs have few equals.

Consider Infocom, the company created in 1979 by Project MAC founder Joseph C. R. Licklider and nearly a dozen other LCS researchers. Infocom sold a peculiar kind of computer game known as "interactive fiction." Best exemplified by Zork, the games were puzzles: The computer would print a description of the "room" that you were in, and sitting at the computer you would type back instructions on where to move and what actions to take.

Though its product may have seemed frivolous, Infocom was a technological pioneer. To accommodate the many different kinds of computer systems in use at the time, Infocom created a virtual computer called the Z Machine. The Z Machine served as a kind of buffer between the programmers and the outside world of mul-

BY SIMSON L. GARFINKEL

Bob Metcalfe learned packet-switching at MIT and launched the Ethernet bandwagon.



Bob Frankston and Dan Bricklin invented the electronic spreadsheet—software that helped businesses see the value of PCs. Their product, VisiCalc, fueled sales of the Apple II.

tiple, incompatible computer formats. The first copy of Zork sold in November 1980 and ran on Digital's PDP-11 minicomputer. A month later, the company was selling Zork for Radio Shack's new TRS-80 microcomputer. In February 1981, Infocom made a version that ran on the popular Apple II—and proceeded to sell 6,000 copies of the game over the next eight months. Infocom ultimately created 35 different games, and in 1984 had sales of $10 million.

Infocom couldn't sustain its growth, though, largely because the company was divided against itself. Although games supplied the revenue, Infocom's management was determined to develop a corporate database tool called Cornerstone. By June of 1985 more than half of the company's 110 employees were working on Cornerstone. The project became a black hole, sucking up development dollars but never yielding a finished product. In December, Infocom finally shut down its business product division and laid off its staff, but it was too late. In June 1986, with just 40 employees left, the company was sold to California-based video-game maker Activision for $9 million. Three years later, all but five of Infocom's 26 employees quit or were laid off, and the tattered remnants of the company were absorbed into Activision's operations. Licklider stayed at LCS, becoming its director. He retired from MIT in 1985 and died in 1990.

While Infocom failed as a business, the company broke important new ground that is still being explored today. Infocom enthusiasts have created Z Machine interpreters for more than 25 different systems—systems as diverse as Windows 95 and the 3Com Palm Pilot. Infocom's philosophy of making programs that run on any type of computer system stood in dramatic contrast to the prevailing way of doing business at the time. But this idea of a "portable environment" has, in the era of the Internet, taken hold in the form of the Perl and Java programming languages.

3Com: Messages Through the Ether(net)

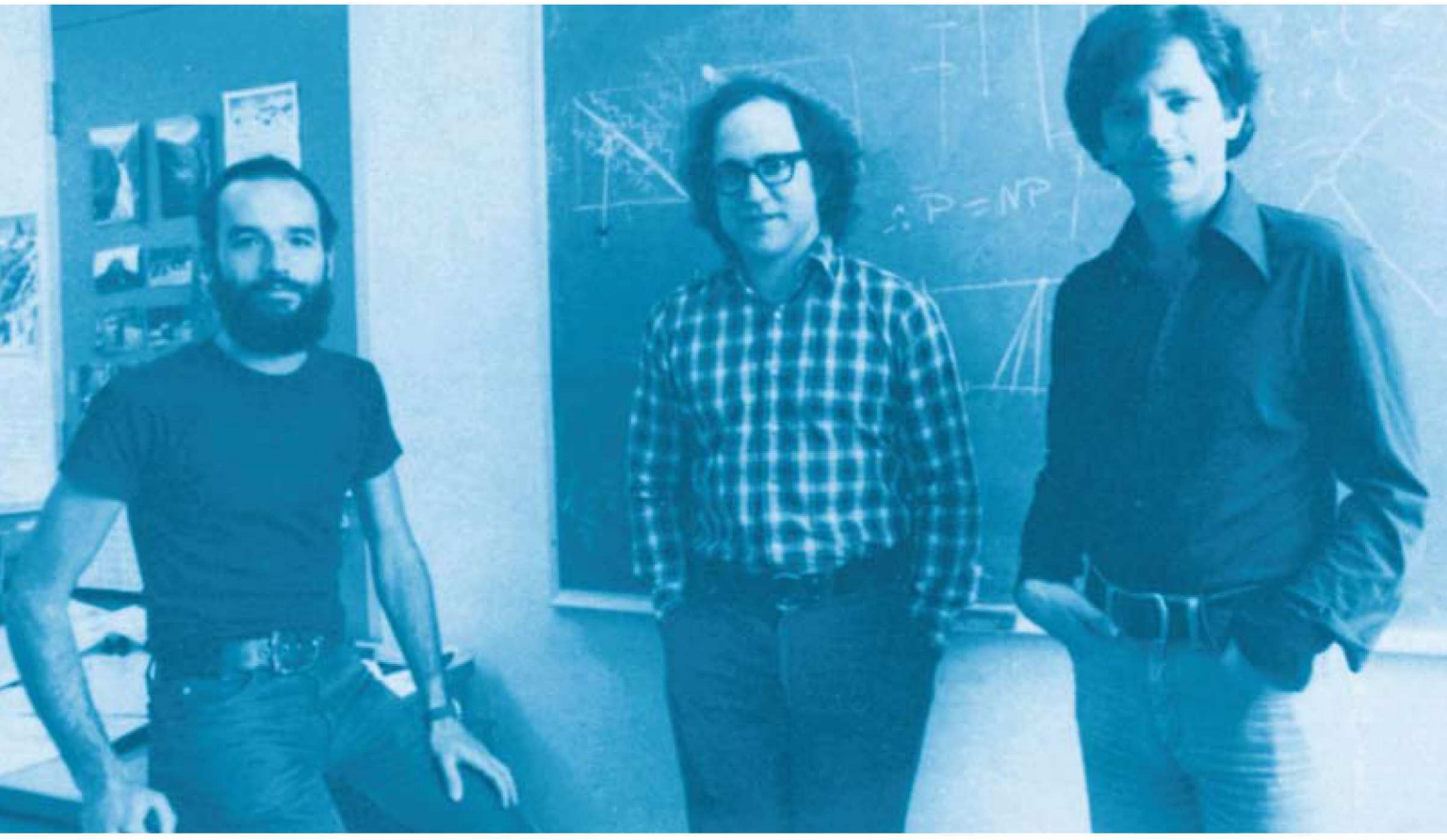
ANOTHER LCS PROGENY WAS NOT ONLY PROFOUNDLY INFLUENTIAL, it also found dramatic commercial success. Bob Metcalfe gained his first exposure to packet-switching techniques while working at Project MAC in 1970. How he found himself at Project MAC is a story in itself: After graduating from MIT in 1969, Metcalfe entered a PhD program up the river at Harvard University. But Harvard didn't have the money to pay Metcalfe's fellowship. To make ends meet, he took a job at Project MAC building a packet-switched network interface card.

Packet-switching is a way of transmitting data that breaks a stream of bits into short segments, called packets; each packet is labeled with instructions for where to go. Packet-switching has caught on in a big way: It is the basis of the Internet.

After leaving Harvard and Project MAC in 1972, Metcalfe migrated west to Xerox's Palo Alto Research Center (PARC), which was pioneering the first personal computers. In 1973, Metcalfe applied the principles of packet-switching to the invention of a local area network technology called Ethernet. Metcalfe convinced Xerox that to be successful, Ethernet would have to be made readily available to all players in the computer industry. Meanwhile, Metcalfe still felt the gravitational tug of MIT. In 1979, he took Dertouzos up on an invitation to return to Boston and work for LCS as a consultant. Metcalfe enlisted Digital Equipment Corp., Intel and Xerox to start the "Ethernet bandwagon"—a commitment to make Ethernet a standard of the Institute of Electrical and Electronics Engineers (IEEE). "IEEE forced Xerox to make its Ethernet patents available for $1,000 per company forever," says Metcalfe.

With the patents available at bargain-basement prices, and with Xerox still unwilling to push the technology into the general marketplace, Metcalfe seized the opportunity. He started a company

LICKLIDER PHOTO COURTESY OF THE MIT MUSEUM CA. 1953



Adi Shamir, Ron Rivest and Leonard Adleman used "public keys" to keep data private. Their instructional demos became hot products.

and licensed the Ethernet technology. Metcalfe's new company—3Com—built network interface cards for all kinds of computers. 3Com went public in March 1984; it now has a market capitalization of roughly $16 billion.

Metcalfe, who eventually left the company he started to become vice president for technology at the International Data Group (IDG) and a columnist in IDG's weekly trade publication, *InfoWorld,* says that the MIT lab "had a great deal to do with the success of 3Com." It's not just that Project MAC was a pioneer in research on packet-switching, the technology at the heart of Ethernet. Equally important was the way LCS functioned as a base for Metcalfe to return to after leaving Xerox. It is doubtful that Metcalfe would have been able to enlist major companies to join his "bandwagon" were he not at an impartial institution.

Software Arts: The First Killer App

IT'S EASY TO FORGET THAT WHEN THE FIRST PERSONAL COMPUTERS arrived in the late 1970s, many people questioned what value such machines would have beyond entertainment and diversion for hobbyists. After a few years, nobody asked that question anymore—thanks largely to the pioneering work of Dan Bricklin and Bob Frankston, who met during the early 1970s while working together in Project MAC and then went on to co-found Software Arts.

"Dan and I had been talking since our MIT days about doing a business," recalls Frankston. Bricklin, who had gone off to get a master's degree at Harvard Business School, discovered firsthand a problem that was ripe for solution by personal computers. Confronted with the typical kind of repetitive calculations that come from the school's case studies, Bricklin devised a program that would automate the work: the electronic spreadsheet. In 1978, Bricklin and Frankston started playing around with a prototype, which they called VisiCalc. They thought at first that VisiCalc would be a "nice home accounting program," says Frankston. "I started working on the real implementation in late November and we were able to demo it in January 1979. It took only a few more weeks—about 40 of them—to start a company, find a real office, buy a Prime 550 [minicomputer], hire some staff, finish the program and ship the product."

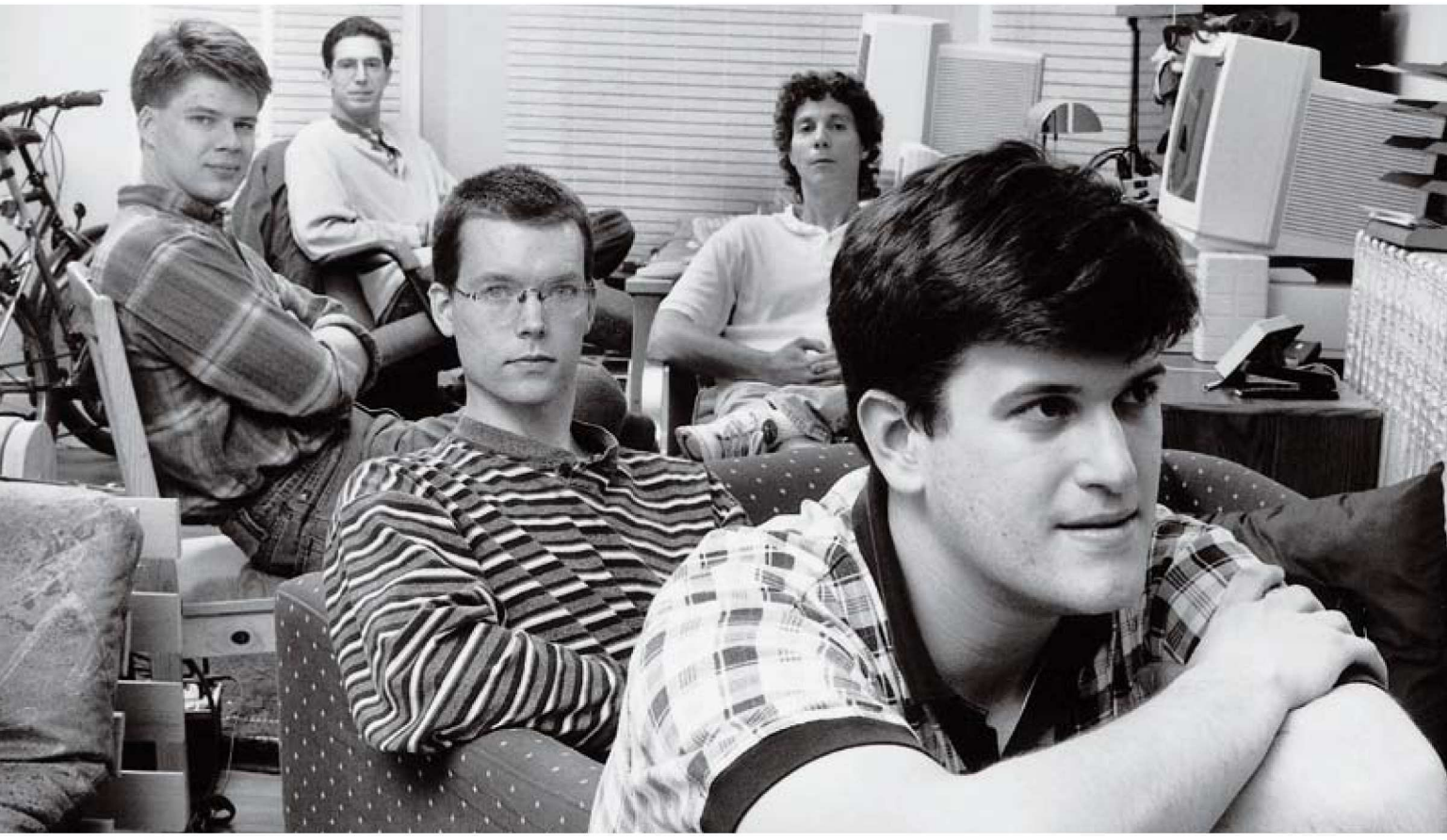
VisiCalc is credited with bringing personal computers to the attention of businesses and fueling the sales of the Apple II computer, the machine on which it first ran. Many of Apple's first customers bought the machines specifically to run VisiCalc; it was the first "killer app." The program let business managers manipulate numbers with undreamed-of flexibility.

Today, alas, Software Arts is no more. Following the introduction of the IBM PC in 1981, domination of the spreadsheet market slipped away from Bricklin and Frankston. The new champion was Lotus Development Corp., with a more advanced PC spreadsheet called 1-2-3. Eventually, Lotus bought Software Arts. Frankston went on to work in high positions at Lotus and Microsoft and is now an advisor to many companies. Bricklin is founder and chief technology officer of Waltham, Mass.-based Trellix, which is developing tools for publishing documents on the Web.

RSA: Masters of Encryption

LIFE ON COMPUTING'S CUTTING EDGE CAN BE A DISADVANTAGE, as it accentuates the difficulty in establishing a market niche. Sometimes, in fact, the technology turns out to be a solution looking for a problem, at least for a while. RSA Data Security—a pioneer in commercializing an ultra-secure form of data encryption known as "public key"—is a case in point.

"We put together a business plan thinking that secure telephones would be the place to start the business," remembers Ron Rivest, who founded the company in 1983 along with LCS col-



Tom Pinckney (right) and the rest of the Exotech crew live at the office—literally. They're part of the next generation of LCS spinoffs.

leagues Adi Shamir and Leonard Adleman. While the company tried to finance and build a prototype, Rivest started working on a software implementation of the RSA encryption system that would demonstrate the technology. In those days, he recalls, "one of the problems with encryption was that nobody understood it at all. So we were developing demonstration software for education purposes—to illustrate what public key could do." After a few years of failing in the secure telephone market, RSA's management realized that secure telephones "were not the best place to start the market." Meanwhile, those "educational" software demos turned into real products, which found a ready market.

RSA's path to riches was not through selling either hardware or software, it turned out, but by marketing "tool kits" that other companies could use easily to build the RSA algorithms into existing products. RSA's first big customer was Iris Associates, which built RSA's technology into a "groupware" program called Notes that it was creating for Lotus. Its second licensee was Novell, which built the technology into its Netware software for running local area networks.

Although Shamir and Adleman soon ended their affiliation with RSA, Rivest stayed with the company, which was sold to Security Dynamics in 1996 for $250 million. Rivest now divides his attention between RSA and his teaching and administrative duties at MIT. He is an assistant director of the LCS—another case of the Lab's ability to nurture and sustain innovators after (or between) their entrepreneurial exploits. Rivest continued to invent cryptographic algorithms, many of which RSA commercialized.

Exotech: The End of Operating Systems?

IN A CRAMPED APARTMENT LESS THAN A MILE FROM MIT, SOME OF the latest crop of LCS-bred entrepreneurs are burning with the same mix of business ambition and technical acumen that has fueled so many previous spinoffs. They have formed a company, called Exotech, whose mission it is to commercialize a high-performance server for the World Wide Web based on the "exokernel" developed by LCS professor M. Frans Kaashoek.

Exokernels are a fundamentally new direction for operating systems—the first break with the original timesharing paradigm perfected by Project MAC 35 years ago. An exokernel, explains Kaashoek, does away with the conventional notion of an operating system altogether. Instead, the idea is for application programs to interact directly and securely with the computer's hardware, without the intermediary of something like Unix or Windows.

Exotech was started by four of Kaashoek's students. They're using the MIT exokernel to build servers for Internet service providers. To launch the business, the group borrowed $90,000, mostly from the parents of company president Tom Pinckney. Then, to cut cost, they all moved to Pinckney's four-bedroom flat in Cambridge.

Today, the need to grow is putting a financial pinch on the company. Says Pinckney: "We have people from MIT, undergraduates, who have summer jobs, part-time jobs, who are interested in full-time jobs. We have one really experienced guy. But we don't have the money to pay them, and we don't have the office space for them to work in. So we have to beg."

The begging may soon be over. In January, Exotech started shaping up to be a real business. It delivered beta software to a customer that Pinckney identifies only as a major Internet service provider serving the Northeast United States. A final version of the product should be on the market in July, he says. With the wind filling their sails, Pinckney and his partners will have an easier time raising money. And the Lab for Computer Science will be able to put another pin on the grand map of computer technology. ◊

Missing the Story

THE ERADICATION OF SMALLPOX.
The double helix.
Genetic engineering.
Penicillin.
Cloning.

It took about one minute for me to jot down a bare-bones list of watershed moments in 20th-century biology—discoveries that have transformed (or will transform) life on every continent in just about every way, as well as creating a whole new industry: biotechnology. I took a considerably longer time trying to figure out what could possibly have been going through the minds of the "experts" convened by the journalism department at New York University (NYU), who compiled and recently published a list of the century's best 100 works of journalism.

According to NYU's judges, the top choice was John Hersey's *Hiroshima.* Also ranking high were Rachel Carson's *Silent Spring,* Woodward and Bernstein on Watergate, Edward R. Murrow on the Battle of Britain, Ida Tarbell's history of Standard Oil, Lincoln Steffens' *The Shame of the Cities,* John Reed's *Ten Days That Shook the World,* and H. L. Mencken on the Scopes trial. The list was heavy on muckrakers and literary journalism about important stories, and light—very light—on science and technology.

Having worked on a couple of these "Best of..." exercises myself, I'm generally not inclined to work myself up into a froth of indignation. Although these lists can be obvious, myopic, self-interested, mystifying, encrusted with cronyism or just plain wrongheaded, they force us into a cultural argument about what we ultimately value.

What we don't value, apparently, is science and its offspring, technology. The absence of science and technology is so glaring that the roster is virtually preatomic, pregenetic—our own little Dark Age. You could argue that *Silent Spring* was about environmental biology and that the Scopes trial was about evolution, but it's a stretch. From *Hiroshima* (number 1) to Hunter Thompson's *Fear and Loathing on the Campaign Trail* (100), the list contains no moon landing, no transistor, no Earth-orbiting communications satellites, no vaccines, no double helix, no computer, no Dolly—no nothing!

The more interesting question is: Why? The list is crowded with a lot of literary heavy-hitters: Tom Wolfe, Joseph Mitchell, Hannah Arendt, Norman Mailer and Susan Sontag, to name a few. Wonderful storytellers and shrewd intellects. Which begs the question: Why don't science and technology attract literary journalists?

It's much easier, for one thing, to understand the drama of warfare or a homicide investigation or an important social trend like the civil rights movement than it is to get at the drama of finding a gene (not to say doing it before someone else). God help the writer trying to sell the importance of finding a gene in fruit flies. If I had a nickel for every time the phrase "and may ultimately lead to a cure for cancer and other human diseases" has been appended to an otherwise utterly basic discovery, I'd have that Tuscan farmhouse I've always wanted.

Some excellent writers have been attracted to the drama of science, and Tom Wolfe was acknowledged for *The Right Stuff* by the NYU panel. But Norman Mailer wasn't acknowledged for *Of a Fire On the Moon,* and while John McPhee made the cut, you hear an awful lot of locker-room grumbling about how he's gone off the deep end of geology.

But the larger problem, it seems to me, is that science and technology are not appreciated and told as *stories*. Not by most writers, not by most editors, and certainly not by the various panels of technophobic experts who can find a place for Grantland Rice in their lists. This most recent list may be accused of several glaring omissions. The rise of molecular biology, so ably documented in Horace Freeland Judson's *The Eighth Day of Creation,* is a collage of stories, a campaign of intellectual brilliance that will tell us more about how we got to the 21st century than any 10 accounts of Joseph McCarthy or the four horsemen of Notre Dame.

When it comes to science and technology, the guardians of the cultural pantheon just don't get it. What's their problem?

Even more unforgivable, however, is the absence of James D. Watson's *The Double Helix.* Though Watson is not, of course, a journalist, this book is as beautifully and shrewdly written as any entry on the list. Furthermore, it elevates the placement of hydrogen bonds to the level of suspense found in an international thriller, and it only involves the single most important biological insight during a century that will surely be viewed by our descendants as the Age of Biology. To overlook it is not a matter of scientific illiteracy; it is an issue of cultural illiteracy, and it's a little harrowing to realize that the custodians of this particular pantheon—academics, broadcasters, media experts—simply didn't get it in such a profound way.

Think back for a moment to the greatest story on the NYU list. One way of viewing *Hiroshima* is that the use of nuclear weapons is the most important story of our time. Another way to think of it is that all the work that led to the splitting of the atom under the University of Chicago stadium by Enrico Fermi was the most misunderstood and underreported story of our time. Remember that when you ponder the absence of an account of cloning from the same list. ◊

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MIT'S MAGAZINE OF INNOVATION
TECHNOLOGY REVIEW

DIANE FENSTER

VIEWPOINT | BY A. D. COLEMAN

The Disembodied Photograph

Photography undergoes a sea change toward the intangible

THINK OF PHOTOGRAPHS AND YOU think of images: photographs in newspapers, magazines and books; photographs on billboards; photographs in your family album, desk drawer or shoebox; photographs on your parents' piano; photographs on your driver's license and passport; photographs as framed posters; photographs as expensive, handmade limited-edition signed original prints in galleries and museums, or perhaps even in your own personal art collection. Which is to say that when you think of photographs you also think of *things*. That makes sense, because until now photographers of all sorts—amateurs, professionals, applied, fine-art—have been object-makers as well as image-makers.

As a result, we've become accustomed to touching, holding, carrying and passing around various forms of actual photographs. Yet, as a result of digital evolution, we now face the imminent diminution of the presence of the photograph-as-object in our lives.

I do not see this as a crisis, but rather as a sea change. It will not happen overnight, but incrementally; it will not require an either/or choice, but will offer us a both/and option. What I'll call "physical photographs" won't disappear; they'll gradually become scarcer, and their production will be increasingly restricted to specific purposes and occasions. As Marshall McLuhan proposed in regard to all supplanted media, their obsolescence will both archaize and estheticize them.

After all, the rendering of photographic images for more than a century and a half in the form of paper sheets coated with a semi-precious metal was not a master plan, simply the result of the fortuitous discovery that silver tarnishes. The reproduction of those images in ink on paper, and the manifold repercussions thereof (ecological, archival, industrial, economic, to name a few), similarly followed no map, just the path of least resistance. Perhaps 95 percent of the photographs with which we've engaged since 1839—news photos,

recording photos (like the ones the insurance company takes of your jewels), studio portraits, family snapshots, advertising pix—took the form of physical objects not because that physicality was essential to their content or function but because we simply didn't know how to encode, store, retrieve or transmit them otherwise.

Now we do, and many of those operations will be replaced by intangible, digital alternatives in the next few decades. Which is to say that in our lifetimes we will most likely cease to think automatically of photographs as things, and engage with more and more—perhaps most—of them as disembodied images and ideas.

What can we foresee in the immediate future? Photojournalism—where the rapidity of image transmission is a crucial factor—has already begun to go digital. So has much advertising, product, and editorial photography. Post-production uses of applied photography—periodical and book layout, the printing and publishing industries—rely increasingly on digital technologies, and our latest publishing medium, the World Wide Web, is entirely electronic. Digital cameras at consumer-friendly prices have begun to compete with analog cameras for the amateur market, and analog photographers who want to explore digital uses can either buy inexpensive scanners to hook up to their home computers or else use a service such as the one provided by Seattle Filmworks, which, in addition to developing your negatives or slides, will transfer them to a computer disk or CD (24-bit color, 768 x 512 resolution) for a mere $5.95 for 36 exposures.

Even the photo booth—the most widely used instrument for self-portraiture in the history of our species—has gone digital. In Gothenberg, Sweden, in 1994, I got from a new model of this commonplace machine a black-and-white digital printout of four versions of my face, instead of the once-standard strip of four or the more recent color equivalents. The quality of the rendering was inferior, even by photo-booth standards, but that was five years ago; I'm sure it's improved. And there's no reason that system couldn't give you the images on a diskette, instead of or in addition to the printout.

These changes should proceed fairly smoothly. There is, however, one area where digitization will create an upheaval: the evidentiary function of the photograph. Digital photography does something extremely problematic in regard to that range of activities: It eliminates the unique physical record—the negative. I am not sure that this sizeable problem can be resolved within or by this technology in any meaningful way. That raises—among other intriguing questions—this one: Can a digital photograph have any legal standing as evidence?

Within the structure of the current technologies, I'd have to say no. So I'll venture to guess that by 2020 analog systems and materials for serious professional use will be far more expensive than their digital equivalents, and will be employed primarily by willful dinosaurs who simply refuse to change (and can afford not to), by artists and photographers who prefer to work in those forms for creative reasons, and by specialists in certain fields—documentary photographers and forensic photographers, say—who wish to generate physical negatives as unimpeachable records.

As for fine-art photography: Digital imagery has already begun to infiltrate this territory. At "The Photography Show," the expo presented in February in New York City by the Association of International Photography Art Dealers (AIPAD), one could find at The Platinum Gallery works by Dan Burkholder, for example, who makes black-and-white analog negatives, scans them, does digital photomontage on the computer, outputs new large-format negatives, and prints them in platinum. Others in this field use digitalization in various ways in their image-making—sometimes just to clean up problem negatives, sometimes to render them as Iris ink-jet prints. No one in the field seems to find this at all perturbing; I'd guess that this constituency—the vendors and collectors of fine-art photography—will adapt to the digital evolution with relative ease, so long as the work remains within traditional precious-object formats.

But there will be challenges to all concerned, even in areas where the digital transition now seems to be smooth. The sharpest challenge will come with the work that's en route, the first wave of inquiry into purely digital photography: unincorporated images, pictures meant strictly for viewing on the computer monitor or in other immaterial forms we can currently only imagine. The logical vehicle for display of digital images—the one we might

argue is inherent to the medium, differentiating it from its predecessors—is the video display terminal (VDT) and subsequent extrapolations thereof.

That's the innovation that'll surprise us—and it won't restrict its impact to the territory of the fine-art photograph, no matter how broadly defined. Most assessments of the potential of digital photography restrict themselves to some variant of traditional media (the digital image output as an Iris ink-jet print on handmade Arches paper, for example) or to the confines of the computer monitor.

Yet of all the components of the computer, the VDT has been least subject to radical invention. Yes, it's gone from monochrome to color, gotten smaller (for laptops and palm-sized PCs) and, for desktops, bigger and flatter. True, with an expensive projector you can throw a slightly degraded version of whatever's on that screen up on the wall in a darkened room. Fact is, though, that for the past two decades, attending to anything displayed on a computer's monitor has approximated looking at a small-to-mid-sized television set.

I expect that to change, and soon. Look for:

- **Paint-on VDT**, some emulsion-based pixellated liquid that can be applied to any surface in any pattern and activated by attachment to a CPU;
- **VDT-by-the-yard**, some cloth-like material that can be cut to any pattern and activated similarly, enabling you, for instance, to wear a shirt on which a programmed sequence of your family-album images is displayed;
- **Digitally produced holographic projection**, 3-D photography, and/or some photographically generated version of virtual reality.

Prepare yourself, that is, for a wider variety of photographic images not attached to objects—or attached to unfamiliar objects. They're just around the corner, and we can look forward to watching paradigm-shift in action as we and our culture come to terms with them.

So sit back and think well beyond photographic scrapbooks. Think about programming imagery for your eveningwear and bedroom walls, as photography detaches itself from the objects we've always associated it with and enters the disembodied realm of the digital.

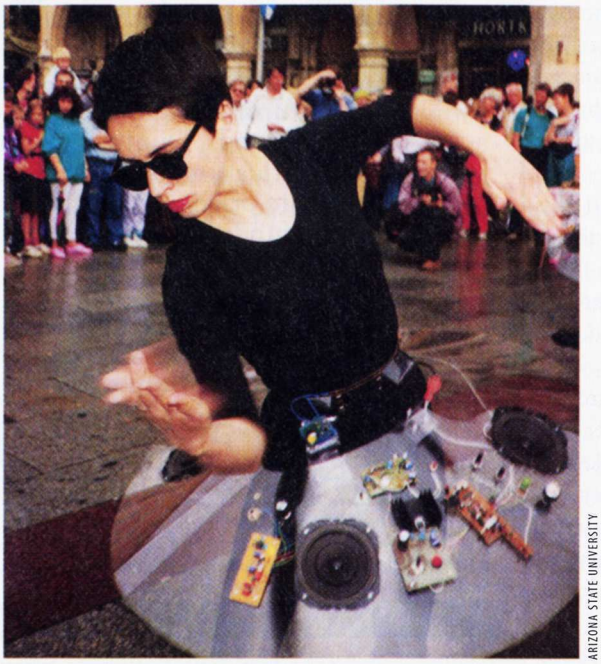
MIXED MEDIA

Dancing in the Fast Lane

Art and technology make slightly uneasy partners

FORGET THE STREETS. IN Tempe, Ariz., this winter, they were dancing in the fast lane of the information highway. At the International Dance and Technology Conference (IDAT), hosted by Arizona State University and its Institute for Studies in the Arts, virtual dancers, real dancers and animated life-forms toe-tapped on sensory stages and keyboard-tapped in galleries. They even sent choreography into cyberspace by Webcasting 27 hours of the conference activities, including panel discussions, performances and demonstrations.

Whether they were dancers using technology or technologists experimenting with art, IDAT performers displayed how far digital technology could serve them in extending bodies, motion and audience perception. Throughout the conference, dancers outfitted in audio uniforms, optical suits and holographic costumes controlled video, sound, projected images and lighting with a flick of a finger or a flex of a knee. After a weekend immersed in demonstrations of how technology can augment displays of artistic human motion, though, it is apparent that despite some dazzling displays of techno-assisted artistry, the connection between dance and technology is not always made.



ARIZONA STATE UNIVERSITY

High-tech tutu: A ballerina from Berlin's Die Audio Gruppe turns movement into sound with an array of electronics.

Of the score of demonstrations at IDAT, *Songs for the Body Electric* by composer Todd Winkler and dancer Gerry Girouard stood out. The athletic Girouard wittily danced on the walls and ceilings of specially constructed boxes with the aid of a simple rubber-tipped pole. Girouard's space-cutting kinetics—handstands and carving arm motions—tripped signals to vary the music and lighting. His digital collaborator in this process is *Very Nervous System*, created by David Rokeby *(see "Dances with Machines," p. 58).*

The disconnect in many of these productions stems in part from a mismatch between the artists and the technologists.

WEB SITE

Geek Show

WWW.SLASHDOT.ORG

Listen closely and you can hear it: the gentle sound of millions of folks nervously scratching their heads wondering just what the heck is going on with the open-source, or "free" software that has suddenly gotten so much attention *(see "Programs to the People," TR January/February 1999)*. There's no better source of information, rumor and opinion on this phenomenon than Slashdot, which titles itself: "News for Nerds. Stuff that Matters."

The creation of 22-year-old Rob Malda—whose nom de Web is "Commander Taco"—Slashdot feels like a geek clubhouse. Malda and others post articles on topics ranging from "the personalities behind Linux" to an essay predicting the arrival of "sexbots" that never have headaches.

Anti-Microsoft sentiment permeates the site; these people know their code and they're offended by what many perceive to be bloated, inefficient software. The "Ask Slashdot" part of the site ranges beyond programming, as knowledgeable participants weigh in on quirky questions like, "What is the bandwidth of a nerve?" (Answer: Well, it depends on what you mean by "bandwidth" and "nerve.")

This is one of those virtual communities you hear so much about. Articles generate a torrent of (mostly) well-informed commentary, much of it signed by "Anonymous Coward"—the epithet Slashdot assigns to contributors unwilling to reveal their names. In one persistent thread, commentators proudly quantify what they call the "Slashdot Effect": the spike in the hit count experienced by Web pages that Slashdot links to. Look to this site as your technical and cultural guide to a powerful movement that is starting to emerge from the computer underground.

—Herb Brody

Consider, for example, choreographer Ellen Bromberg's *Falling to Earth*, a piece that was created on the Intelligent Stage—a sensory space that registers and responds to input through video, audio and cueing systems. Artist/technologist Doug Rosenberg projected lyrical imagery and descriptive text on S-curved drapes and the dancers' bodies.

The adolescent narrative (movie-of-the-week stuff about growing up with alcoholic parents) and New Age-y music, however, reminded us that no matter how well the technology is executed, without equal artistic elements, beauty is only screen deep. Not that making technology and artistry equal partners is without its own dangers. In *Inner Spaces of Drifting*, video artist Rogolja Wolf and choreographer Jennifer Predock-Linnel offered mesmerizing aquatic images on the screen and a smart dance trio, which seemed lost in the dark at the bottom of the horizontally divided set. Screen and stage worked here as partners of equal but separate strength, forcing the audience to choose between watching one or the other: a two-ring circus.

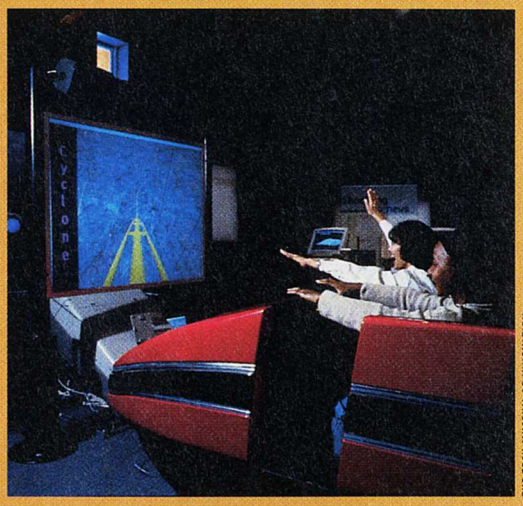
Others at the conference more successfully integrated technology with art. In her hallucinatory dance, *Communion*, Montreal dancer/choreographer Isabelle Choiniere explored ancient and contemporary nuances of dance within a tableau-like form. As electronic whispers invoked the goddesses Isis, Diana and Hecate, Choiniere—clad in a sensor-laden, Day-Glo leotard—reproduced her image on the scrims in front of and behind her. With majestic movements, she evoked this century's dance goddesses. While sine waves undulated on the scrims, she drew a molten voice from her red-lit mouth. In slow dissolves, Choiniere seemed to incarnate the temple dancer, body builder, exotic dancer.

In Troika Ranch's powerhouse *In Plane*, the only livestock was a two-legged creature: Dawn Stoppiello, in electronically augmented garb. The outfit is called a MidiDancer sensory suit by its inventor, Mark Coniglio. Coniglio—Troika Ranch's composer and co-artistic director—positioned sensors within the garment that encoded information and sent it to an offstage computer. Stoppiello thus controlled the dynamics and timing of Coniglio's music and video projec-

MUSEUM

The Tech: World-Class Fair

Designed for brain-grabbing glitz, The Tech Museum of Innovation's new facility in San Jose, Calif., is the first of America's next generation of museums—conceived from the ground up in this age of real-time multimedia interactivity.



THE TECH MUSEUM OF INNOVATION

Thrillsville: Kids test-ride their virtual roller coaster.

The Tech's brashly colored structure, resembling a giant orange-and-blue juice press, brings to mind a pavilion at a World's Fair of yesteryear. Inside, its highly entertaining exhibits—most of them corporate-sponsored, World's-Fair-style—inform about the latest developments in health care, automation, telecommunications and of course computers. Aimed at visitors from about the sixth grade and up, the museum is a mutable fair of up-to-the-minute technology bursting out of Silicon Valley, at whose foot San Jose beckons. The Tech's vice president for exhibits, Emily Routman, welcomes comparison of the 132,000-square-foot, three-level structure to a mini-World's Fair. Like such venues, she says, The Tech focuses "not just on technology per se, but on the impact of technology on people, and of people on technology."

In the four permanent exhibit areas, humans and computers interact as old acquaintances. A variety of multimedia experiences await: Design, then "ride," a virtual roller coaster—the Tech Cyclone. Sit for a 3-D digital scan of your head, which you can then manipulate for artistic (or not-so-artistic) effect. Participate in a virtual wheelchair race. Examine the inside of an actual clean room, where microchips are born.

Cognoscenti of Silicon Valley politics will appreciate the symbolic import of placing exhibits sponsored by rival chipmakers Intel and Advanced Micro Devices on different floors. The Tech's basement gallery for temporary exhibits—called "Center of the Edge"—provides additional fodder for amateur Valley-ologists. The initial exhibit this winter and spring gave the public its first glimpse of work by Interval Research—the usually hush-hush tech think tank funded by Microsoft co-founder Paul Allen. The firm's emphasis on human-factors research showed in an exhibit allowing viewers on a giant turntable to see their virtual surroundings in any of several remote locations on earth.

True to the character of the industry from which it was born, The Tech continually changes. It began as an initiative in 1978 by members of the Junior League of nearby Palo Alto. In 1990, the museum made its debut in temporary quarters in an old warehouse building downtown. The new quarters, which opened last October, were made possible by the efforts of Peter Giles, president and CEO of The Tech since 1987. Even the more permanent exhibits are works-in-progress. By the time these words appear in print, for example, the Tech Cyclone will have been upgraded to incorporate the latest software from Silicon Graphics to yield more detailed imagery.

Occasionally, in making technology accessible, The Tech may gild the microchip. An exhibit examining the scientific viability of video clips from sci-fi movies, for instance, features superfluous commentary by a team of pseudo-Siskel-and-Ebert movie critics (rendered obsolete by the real Gene Siskel's recent demise). Still, this museum sets an elevated standard for showing high-tech to be intriguing, engrossing, even awe-inspiring—thanks to the very technologies it invokes. **—Steve Ditlea**

tions. She raced like a speed skater against her own image.

Since 1993, Troika Ranch has been an incubator for posing what was perhaps the main question of the conference: Which comes first, the dancer or the technology? Based on the IDAT showcase, techno-artists are still struggling to solve this riddle.

—Merilyn Jackson

NET NUGGETS

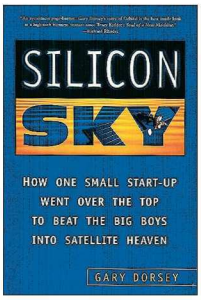
Netsurfer: We have been resisting the urge to plug Netsurfer Communications. They gave our Web site a nice review in *Netsurfer Science*, one of their three free e-zines, and we didn't want anybody to get the wrong idea. But why deprive you of one of our favorite resources? The Netsurfer Digest reminds us more or less weekly that the Web is a rich repository of news, culture and oddity. Who but Netsurfer would point us not only to fantastic online art galleries and in-depth discussions of political events, but also to a site devoted entirely to moist towelettes? And the recently-launched Netsurfer Books tells us what we might want to read on paper—if we could tear ourselves away from our Web browsers.
www.netsurf.com

Internet Patent News Service: Got a beef with the patent system? So does Gregory Aharonian, whose (almost) daily newsletter flames the U.S. Patent Office for everything from the way it compensates examiners to its alleged allowance of spurious software patents. Aharonian's edgy epistles are the best source around for inside baseball on the legislation, politics and people that make the patent system go. To subscribe, send the message "NEWS" to **patents@world.std.com**

Household Cyclopedia: Set the way-back machine for 1881. This tome on the "useful and domestic arts" tells how to make gunpowder, cook up a mess of gruel, and amputate a limb, among many other tasks. Browsing here reminds us just how self-reliant people once had to be (and will be again, if Y2K doomsayers have it right).
http://members.xoom.com/mspong/

Uncommon Laborers

SILICON SKY: How One Small Start-up Went Over the Top to Beat the Big Boys into Satellite Heaven
by Gary Dorsey
Perseus Books, 352 pp., $26



EVEN BEFORE THE APOLLO missions ended, rocket science had begun to lose its Olympian aura. The Challenger explosion in 1986 completed the process, making many in the U.S. aerospace industry look like reckless bumblers. But with the film "Apollo 13," the HBO miniseries "From the Earth to the Moon," and now Gary Dorsey's *Silicon Sky,* the engineers behind America's successes in space are once again being cast as heroes.

Dorsey's book chronicles the rise of Orbital Sciences Inc., the Virginia startup that invented the Pegasus rocket, the nation's first new launch vehicle in decades. In the early 1990s the company wooed investors with a promise to launch its own network of small, cheap communications satellites, bringing a global wireless network to market long before competitors such as Motorola. By 1998 it had succeeded, thanks in part to the brashness and savvy of Orbital co-founder David Thompson.

But Dorsey attributes most of Orbital's success to its engineers. In the tradition of Tracy Kidder and Richard Preston, Dorsey played historian and anthropologist to this high-tech tribe, as they designed and tested Orbital's first diminutive satellites (built small so that a Pegasus rocket could launch six at once). In the face of financial uncertainties and technical setbacks, only the engineers' quasi-religious devotion to their work staved off failure, Dorsey concludes.

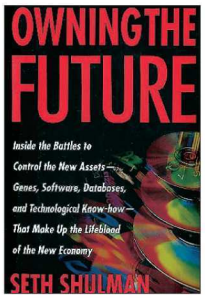
His search for the sources and costs of such devotion make compelling reading. At first the hotshot engineers were simply thankful for the opportunity to prove themselves. They felt energized by the entrepreneurial small-company atmosphere, so different from the "musty dens of traditional aerospace," those "decrepit buildings filled with tired old men and dusty mainframes."

The problem was that the technical challenge of miniaturizing and programming the satellites' components turned out to be far more devilish than the company's executives had imagined. As launch dates slipped and investors grew antsy, demands on the engineering team escalated beyond all reason, straining marriages and leading one mid-level manager to joke that "a holiday is one of those days when the mail's not there when you get home from work."

How team members adapted, or failed to adapt, to the unrelenting pressure forms the bulk of Dorsey's fascinating narrative. Orbital emerges with proven technology and respectable revenues, with the personal sacrifices, according to many of Dorsey's sources, justified by the grandeur of the cause. "We can't keep working this hard," says one. "[But] there's nothing easy about what the company is trying to do. We're not common laborers, we're satellite engineers."

Charging Rent on Dreams

OWNING THE FUTURE
by Seth Shulman
Houghton Mifflin Company, 249 pp., $25



AROUND MIT, JEROME Lemelson is a hallowed name. The late inventor's 500-plus patents (more than any other individual save Thomas Edison) earned him enough to endow the Institute's $500,000 Lemelson Prize for technological innovation. But to Seth Shulman, a journalist who is a frequent contributor to *TR* and a former Knight Science Journalism Fellow at MIT, Lemelson's success epitomizes a growing scandal in the United States: the privatization of the "conceptual commons."

Shulman writes that Lemelson was often the first to file for a patent on ideas circulating in the intellectual air, such as combining videotape and the TV camera in the hand-held camcorder. Even if he never built a working model or his patent was issued belatedly, the priority of his claim allowed him to hold whole industries hostage, Shulman argues. "Lemelson's technique—one he repeated throughout his career—was to demand royalties from the companies with existing products that could be construed as infringing his broad claims."

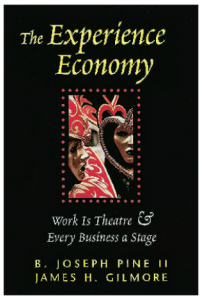
"Charging rent on dreams," Shulman calls it, and Lemelson is hardly the only one criticized for this practice in his book. Physicians patenting surgical procedures, seed companies suing farmers for selling part of a genetically engineered crop to neighbors for seed, and pharmaceutical firms purveying drugs derived from tropical plants without paying a cent to the indigenous tribes who first noticed their curative powers all come under Shulman's lens. His book amounts to an eloquent warning against what he describes as "an uncontrolled stampede to auction off our technological and cultural heritage."

The central problem, as Shulman sees it, is that the U.S. Patent Office has become remarkably generous in its evaluation of the traits that make an invention patentable, such as "novel," "non-obvious," and "made by man." Many patented concepts today, such as the nucleotide sequence of a gene or a mathematical algorithm in a piece of software aren't inventions at all but instead inhabit a nebulous zone experts call "actionable knowledge." Far from spurring innovation, as the patent system was designed to do, the patenting of actionable knowledge threatens the free exchange of information and gives individuals and corporations a legal chokehold over ideas that should benefit all, Shulman contends.

The alternatives, unfortunately, are themselves non-obvious. Since the patent system is still mired in the language of land ownership—as evidenced by the term "intellectual property"—one solution might be to create the conceptual equivalents of national parks and zoning laws, he suggests. It's an intriguing idea, and one that deserves further exploration. Somehow, we should all profit from the private redevelopment of the conceptual commons.

Now Playing: Your Business

THE EXPERIENCE ECONOMY:
Work Is Theatre & Every Business a Stage
by B. Joseph Pine II and James Gilmore
Harvard Business School Press,
336 pp., $24.95



Bookstore shelves are filled with management books that stretch good metaphors to the breaking point. Business is school (the "learning organization"). Business is a machine (reengineering). Business is digital information (the "new economy"). But *The Experience Economy* has a more elastic organizing concept—or at least one that holds up for a few hundred pages. In this era of standardization and mass consumption, consultants Joseph Pine and James Gilmore believe, more and more people are willing to pay for memorable *experiences,* not just well-made products.

Today's most innovative and profitable companies, they argue, sell the theatrical rather than the tangible—experiences "rich with sensations, created within the customer," rather than traditional commodities, goods and services. Starbucks coffeehouses, for example, didn't become almost as ubiquitous as McDonald's because of the coffee; Americans coped for decades without someplace to spend $2.95 on a grande caramel macchiato. Rather, customers at Starbucks are paying for staged experiences, Pine and Gilmore would say. The company treats patrons to poetry on its wallpaper and tabletops, jaunty apron-clad performers behind the espresso machine, and an interior ambience that's both cozy and slick, marked by earth tones, brushed steel and retro music (also for sale). Few people leave without feeling a little more affluent, sophisticated or jazzed.

Business as theatre may not be a wholly original metaphor, but Pine and Gilmore present it in an entertaining and usable way. If the workplace is a stage, they point out, effective performances depend on entertaining scripts, expert direction, attractive sets and good acting. "To engage a customer in the Experience Economy, act as if your work depended on it! It is the *act of acting* that, in the end, differentiates memorable experiences from ordinary human activity."

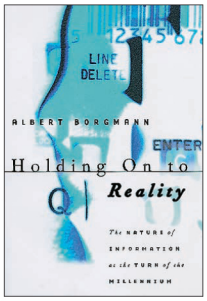
Disney takes these maxims literally; employees are called "cast members" and must stay "in character" in guest areas. But Pine and Gilmore argue that even the most mundane businesses can add value to their products and services by delivering them with panache.

Transformations—experiences that change us—are even more valuable, the authors add. Good multimedia software, for example, creates "imaginary worlds that have a special relationship to reality—worlds in which we can extend, amplify, and enrich our own capabilities to think, feel, and act," as one expert on human-computer interaction is quoted. *The Experience Economy*, with its own well-developed theme and enriching examples, may transform more than a few managers.

Information: Is Less More?

HOLDING ON TO REALITY: The Nature of Information at the Turn of the Millennium
by Albert Borgmann
University of Chicago Press,
224 pp., $22

TOTALITARIAN RULERS aren't the only people who get nervous around new information technologies. In his 1986 book *The Cult of Information,* cultural critic Theodore Roszak fretted that the flood of electronic data would drown genuine thought and ideas. "It would be a great loss if, by cheapening our conception of experience, memory, and insight, the cult of information blunted [human beings'] creative powers," Roszak wrote.



Albert Borgmann, a philosopher at the University of Montana, is the latest to sound the so-called humanist alarm against the encroachments of the information revolution. In *Holding On to Reality,* he divides information into three classes—natural, cultural and technological—and argues that only the first two are "spare and austere enough to engage memory and imagination." Technological information, from this point of view, is a usurper that substitutes transistors, Boolean logic and pixels for direct experience and learning.

It's true that a thunderstorm, a trembling leaf or any other piece of natural information can speak with "unsurpassable eloquence," as Borgmann writes. And maps, manuscripts, musical scores and other items of cultural information rank among humanity's greatest innovations. But it is elitist and puritanical of Borgmann to cast computer-mediated information as something merely parasitic on cultural information. In Borgmann's world, a person who wanted to get a flavor of Leonardo da Vinci's thinking would have to spend millions on an original manuscript, study classical Italian and learn to decipher Leonardo's mirror-script. While it may bring Leonardo into thousands of homes, from Borgmann's vantage point the $39 CD-ROM with high-resolution images and translations from a Leonardo notebook merely "cheapens" the real thing.

There *is* a glut of information. But critics such as Roszak and Borgmann fail to recognize that the only way to deal with the glut is more information—especially information like the Leonardo CD-ROM or this book review, which directs audiences to other information and helps them decide whether it should be consumed now, stored or discarded. If you're open to the idea that less-informed societies are better off, or that new media technologies impoverish rather than enhance information, read *Holding On to Reality.* Otherwise, hold off. ◊

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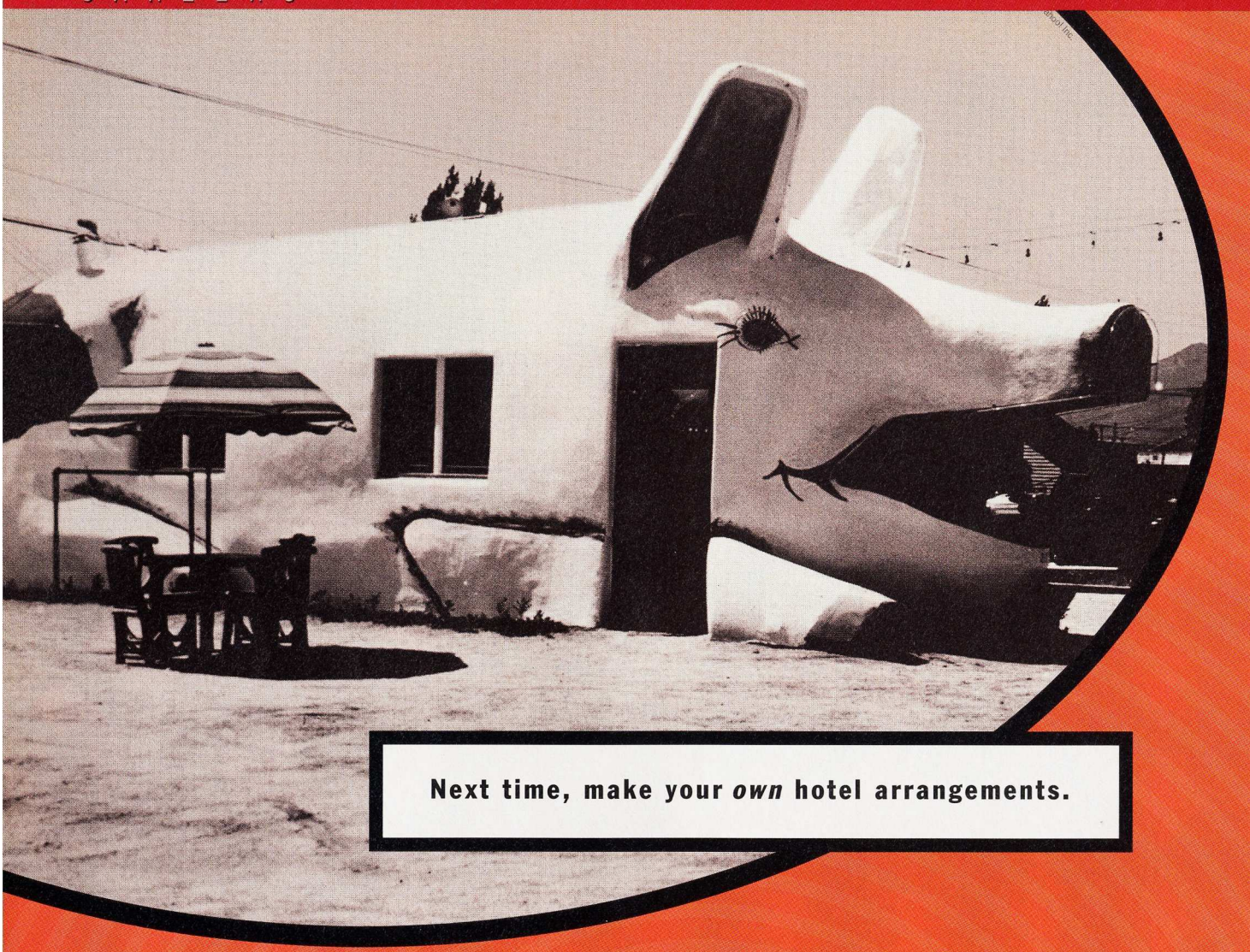

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THE SCHENECTADY MUSEUM

Cutting the Glare

Katharine Burr Blodgett's "invisible glass" helps us see

Camera lenses, telescopes and a host of other optical devices owe their efficiency to glare-proof glass. The material has been dubbed "invisible glass," but its inventor, as the first female research scientist at General Electric, was very visible indeed.

Katharine Burr Blodgett was born in Schenectady, New York, in 1889, the second child of a G.E. patent attorney who died before his daughter's birth. On a Christmas vacation at age 18, she visited the Schenectady research facilities of her father's former employer, where her tour guide was the chemist (and future Nobel Laureate) Irving Langmuir. Langmuir encouraged the teenager to pursue her studies in science, and she did; earning a master's degree from the University of Chicago the following spring helped Blodgett earn a spot in Langmuir's lab. After that, except for the two years she took off to get the first physics PhD ever awarded to a woman by Cambridge University, Blodgett spent the whole of her 45-year career at G.E.

Witty and gregarious, the petite researcher—known to all at G.E. as Katie—made a big splash in the last week of 1938. That's when the company announced Blodgett had found a way to treat glass so that 99 percent of the light hitting it would penetrate, rather than reflecting off the surface. Blodgett's process grew from Langmuir's discovery years earlier that when he spread certain substances on water, a film one molecule thick formed; by dipping a plate through the film and then pulling it out again, Blodgett found she could deposit single-molecule layers on solid surfaces. Coating a sheet of ordinary glass with 44 layers of liquid soap molecules virtually eliminated glare.

What the press called "invisible glass" landed Blodgett in *Time, Life* and *The New York Times*. Though the soap coating was too soft for commercial application, G.E. made Blodgett's findings public; other researchers soon found ways of making durable films that to this day coat lenses, shop windows, picture glass and windshields. In the meanwhile, spurred by the Second World War, Blodgett turned her attention to such military applications as airplane de-icing and smokescreen machines.

Though her contributions to science, technology and G.E. have been recognized by a multitude of citations and awards, there was at least one critical omission: The author of a 1953 *Science* article titled "Seventy-five years of research in General Electric" admiringly mentioned almost every man to pass through the company's labs—but not Katie Blodgett. ◊

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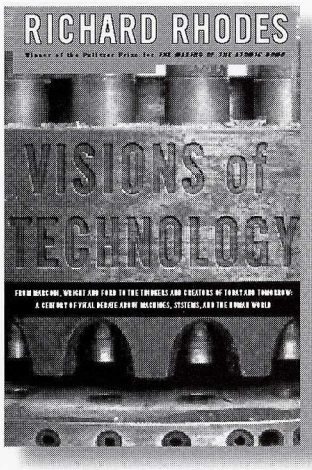

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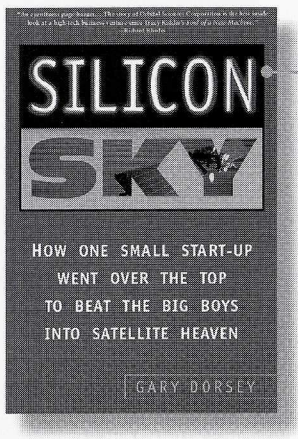

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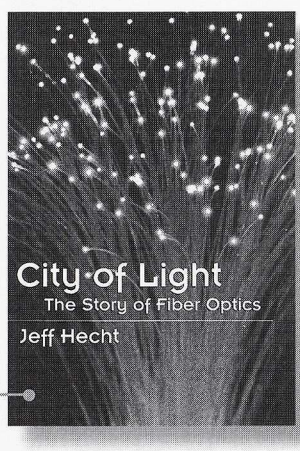

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